FACTORS AFFECTING THE CLARIFICATION OF COLLIERY WASTEWATER

BY

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THESIS SUBMITTED TO THE C.N.A.A. IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

DEPARTMENT OF CHEMICAL ENGINEERING
THE POLYTECHNIC OF WALES
TREFOREST, PONTYPRIDD
MID-GLAMORGAN,
WALES, U.K.

IN COLLABORATION WITH THE NATIONAL COAL BOARD (N.C.B.)

SEPTEMBER, 1984.

DECLARATION

This is to certify that neither this thesis nor any part of it has been presented or being concurrently submitted in candidature for any other degrees.

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Dated. September, 1984.

CERTIFICATE OF RESEARCH

This is to certify that, except where specific reference is made, the work in this thesis is result of the investigation of this candidate.

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ACKNOWLEDGEMENTS

I would like to take this opportunity to express my sincere gratitude to Dr. C. Davies and Dr. G.J. James for their guidance and supervision in all respects over the course of this research work.

I wish to thank the Staff at both N.C.B. Laboratory, Pontypridd, and those at the South Celynen Coal Mines for supplying the colliery wastewater.

My sincere appreciation is also due to all the technical staff of the Department of Chemical Engineering for their help in the construction and maintenance of the experimental apparatus, and also to Mr. S. Lewis and Mr. G.S. Virdi.

I am also thankful to the technical staff at the Department of Mechanical and Production Engineering for allowing me to use their Microscopy Laboratory.

I do acknowledge the help of the Chemistry and Physics sections of the Department of Chemistry for the use of X-ray diffraction, Scanning Electron Microscope and Perkin-Elmer Spectrophotometer equipment.

Finally I do appreciate the endurance and patience of my family during the preparation of the thesis.

NOMENCLATURE

A	Cross sectional area of the electrophoretic cell	(m^2)
D	Dielectric Constant	
E	Potential Gradient	$(\mathrm{Volt}\ m^{-1})$
I	Current in the electrophoretic cell	(Amp)
M	Magnification ratio between the monitor screen and the magnitude of the objective lens.	
R	Resistance of the substance in the electrophoretic cell	(ohm)
V	Voltage across the electrophoretic cell	(volt)
X	Distance travelled by the particles as observed on the television screen	(m)
l	Effective length between the electrodes	(m)
t	Time taken to travel the distance on the television screen	(s)
u	Velocity of the particles	(ms^{-1})
x	Distance travelled by the particles in the electrophoretic cell	(m)
λ	Electrical conductivity	$(\mathrm{ohm}^{-1}\ m^{-1})$
μ	Electrophoretic Mobility of the particles	$(m^2 \mathrm{volt}^{-1} s^{-1})$
v	Viscosity	$(\mathrm{Kg}\ m^{-1} s^{-1})$
ξ	Zeta potential	(volt)

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ABSTRACT

Investigations were initially carried out to characterize the materials present in shape, mineralogical and chemical composition, and particle size distribution.

A micro-electrophoresis apparatus was constructed to determine the electrokinetic parameters of the colliery waste-water.

The origin of the surface charge which forms on minerals immersed in water is important in flocculation. The nature of the charges on the fines were determined to be both positive and negative. This could be due to the coating of the particles by the addition of the froth flotation reagent used.

The electrophoretic mobilities of the particles were measured at the various pH values and at different depths within the electrophoretic cells. These values of the electrophoretic mobilities were used to calculate the values of the zeta potential by the application of Smoluchowski's equation.

The iso-electric point (IEP) and the zero point of charge (ZPC) were also investigated and found to coincide at all the different levels of depth within the electrophoretic cell.

Finally the colliery waste-water was clarified successfully by flocculating it using the polyacrylamide solution.

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CHAPTER 1

INTRODUCTION

The objective of this research is to obtain fundamental data on the properties of the colliery fines remaining in the colliery waste-water after the coal has been subjected to the conventional washing operations at the South Celynen Coal Mines Newbridge, South Wales. The data may then be applied to optimize the clarification of the waste-water. The clarified discharge would minimize river pollution in this area.

Most contaminants in waste-water are solid particles and many of these solid particles are stable colloids. Consequently the treatment of the waste-water requires effective solid-liquid separation. Furthermore, coagulation or flocculation which involves the chemical destabilization of particulates and the physical transport of the destabilized particles to form larger aggregates is an essential component of all waste-water treatment systems(1).

The most important and the most overlooked characteristic of waste-water particulate matter is its size.

Particle size determines the transport of materials in solid-liquid separation processes. Surface area influences the chemical reactions of particles including interactions with flocculants and coagulants and adsorption contaminants.

The science of particle size is related to both particle geometry and surface interaction with the surrounding fluid.

Quantitative knowledge of the geometric and chemical properties of particles provide the basis for the design of a solid-liquid separation process. In practice, theory has not been developed sufficiently and empiricism still continues to play an important role(2).

Interaction between fluid and particles is a complex process which is highly dependent on particle size and shape. Surface effects become increasingly important as particles decrease in size and develop large surface area.

A precise definition of particle size requires the knowledge of the boundary surface which separates the particle from its surroundings(7). Where strong crystalline or intermolecular forces are involved, it is relatively simple to differentiate particles from their background. But where there are weak interactions such as with clay, silica gel and aluminium and iron hydroxides in aqueous slurries, it is more difficult to decide where a particle terminates and the surrounding fluid begins. Shearing forces and their relation to particle break-up are important in differentiating between strong and weak particles. Shearing forces easily remove liquid from contact with the particle surface where the fluid is loosely attached to the solids and the energy barriers are small. With fragile materials it is necessary to resort to indirect methods of size analysis. Particle degradation can often be damaging to the efficiency of industrial solid-liquid separation processes. Centrifugal pumps, transportation of fluidized coal and minerals, mixing of flocculants with slurries can all lead to particle break-up.

It is the objective of particle science to translate microscopic properties of statistically significant groups of particles into macroscopic properties of the systems which may be dispersed (slurries) or packed (cakes or beds).

Properties of particulate systems relate to the nature of individual particles and to their mutual interaction in concentrated suspension. Analytical methods stress the importance of dispersion and isolation of individual members of ensembles so that each can be measured independently. Important as characteristics may be for single particles, the nature of closely packed particles in beds is of equal or greater significance in separation operations.

A slurry may consist of a mixture of individual particles and agglomerates. Sedimentation behaviour is a function of the actual state of agglomeration. Thus particle analysis would not yield information pertinent to the design of a clarifier Reflecting the problem of definition and the widespread appearance of particles in diverse systems terms such as silt, gravel and dust are encountered.

Large particles can easily be observed visually and the laws of geometry can be applied. If the size reaches the molecular range, statistical mechanics can be used to describe the system. In the intermediate range of colloidal and fine particles, no universally satisfactory method is available to define the system.

The particle distribution in most solid-liquid suspensions encountered in industrial applications extends over several orders of magnitude. The removal of a significant proportion of the large particles is accomplished relatively easily by screening or sedimentation. However, fine particles cannot be removed efficiently by such methods. For a successful separation by sedimentation, aggregation of fine particles into large more readily settleable aggregates is essential.

The rate of aggregation and the nature of the particle concentration and types of electrolytes, flocculants and pH., Bodman et al.(3) found experimentally that the settling rate of suspensions of titanium oxide (TiO_2) in water is a strong function of pH, salt concentration and flocculating agent concentration. Coagulation is also used to assist in other solid-liquid separation methods.

When two phases are in contact, as in a suspension (solid-liquid) there develops a difference in potential between them(4). When one of the phases is caused to move tangentially past the second phase thereare observed a number of phenomena which are grouped under electrokinetic effects. There are four distinct effects depending on the way in which the motion is induced and they are; electrophoresis, electro-osmosis, streaming and sedimentation potential.

In most electrokinetic pheomena a fluid moves with respect to a solid surface; the exception is electro-osmosis. This thesis will be concerned with the determination of the relationship between the velocity of the fluid and the electric field in the interphase region. The electric field will be partly determined by the surface charges on the solid and in the liquid but may also include an externally imposed field.

The relationship between the potential or the electric field at any point and the number of charges is given by the Poisson equation. The charges themselves will respond to three sorts of forces: electrical potential, the diffusion force tending to smooth out concentration variations and the bulk movement of charge carried along by the flow of the liquid (convective transport).

Even using vector calculus and high-speed computer solution of the resulting differential equations it is necessary to make a number of significant simplifications to treat highly idealized models of the real experimental conditions(4).

Theoretical treatments generally assume that the solid is either a sphere, a cylinder or a large flat plate, or rarely a disc or an ellipsoid. The liquid is assumed to be Newtonian(2), and moving sufficiently slowly so that turbulence and other non-linear effects are absent.

The most important concept which is introduced is that of the plane of shear. This is an imaginary surface which is considered to lie close to the solid surface and within which the fluid is stationary. In the case of a particle undergoing electrophoresis the surface of shear forms a sheath which envelopes the particle. All the material inside the sheath forms the kinetic unit so that the particle moves along with a certain quantity of the surrounding liquid and its contained charge. Measurement of the electrophoretic mobility therefore gives a measure of the net charge on the solid particle.

Analysis of the forces on the solid or the liquid can be carried out in terms of either charge or electrostatic potential. In the latter case the calculation of the average potential in the surface of shear is performed and this is called the electrokinetic or the zeta potential.

Another limitation of the concept of the surface of shear is the assumption that the fluid in the neighbourhood of the surface retains its bulk properties right up to the surface(2,4) such that the viscosity then becomes infinitely large just inside the shear surface. This limitation can be replaced by a less restrictive one, but at the cost of the lack of definition of the zeta potential. This procedure is justified because the effect of the electricity on the viscosity is probably not as large as was first believed.(4,10)

Many of the important properties of colloidal systems are determined directly or indirectly by the electrical charge or potential on the particles. The potential distribution determines the interaction energy between the particles, and this is often responsible for the stability of the particles towards coagulation and flocculation. It is also possible to correlate the zeta potential with the sedimentation behaviour of colloidal systems and the flotation of mineral ores(10). If the zeta potential is an indicator of the electrical state of the double layer, then when it approaches zero, sols should become unstable and this should lead to clarification (1,2,4,7,10). This has been demonstrated where inorganic electrolytes have been used to lower the zeta potential of industrial wastes(5,6).

Despite the limitations of both these procedures they remain the most valuable available at present. Some recent developments(8) in the measurement of semi-conductor properties are very promising and may provide an alternate accepted technique for measuring total double layer potentials.

Work up to the early 1950's has been reviewed by Overbeek(9) and this work will be taken as essentially the base line for this review. There are many situations in which the zeta potential is used as a parameter in its own right. These include characterizing the outer diffuse part of the double layer and hence is valuable for discussing the interaction between particles or the flow of liquid through membrane pores or porous plugs.

The importance of zeta potential measurement to an understanding of the mineral-water interface has been reviewed by Mackenzie(10), Haydon(11) and Overbeek(12) and on the properties of the oxide mineral-water interface by Parks(13,14).

There is still unfortunately a large gap between the theoretical aspects of the electrical double-layer structure and the practical application of these theories to industrial processes.

LITERATURE SURVEY

CHAPTER 2

2.1 INTRODUCTION

Clarification involves the removal of solids from a relatively dilute stream containing difficult to filter colloidal materials. Frequently, admixes of filter-aids are added directly to the slurry to reduce the resistance of the fine particles. This method of clarification thus involves the study of the solid-liquid separation process.

The solid-liquid separation process involves the separation of two phases, solid and liquid from a suspension(2,7,15,16,17,18). It is used in many processes with the aim of :

(a) recovering the valuable solids, (the liquid being discarded);

(b) recovering the liquid, (solids being discarded);

(c) recovering both solids and liquids;

(d) recovering neither (but for example to prevent water pollution).

An ideal solid-liquid separation process would result in a stream of liquid going one way and dry solids the other way. Unfortunately, none of the separation devices works perfectly (2,7,18). This imperfection of separation can be characterized in two ways. The mass fraction of the solids recovered is called the separation efficiency and expressed as a percentage, whilst the dryness of the solids recovered may be characterized by the moisture content which is percentage by weight.

2.2 SOLID-LIQUID SEPARATION PROCESSES

The term filtration implies a narrow concept while solid-liquid separation designation reflects better the realities confronting engineers with the need for effecting separation of particulates from liquids(2,7,15). Solid-liquid separation includes a variety of operations ranging from pretreatment of slurries through thickening to cake deliquoring.

There are considerable differences in the solid-liquid separation field since the essential solid-liquid parameters such as permeability and porosity must presently be obtained anew for every material. The number of combinations of satisfactory operations is so large that finding the best process is difficult.

If the liquid is constrained and particles can move freely within it, due to fields of acceleration, then the separation processes are known as sedimentation and flotation (15,16). Tiller(2), Svarovsky(7) Coulson and Richardson(15) and Perry(16) have discussed all the various methods of solid-liquid separation processes.

There are certain fundamental concepts which are essential to the understanding of the solid-liquid separation processes and among these fields of study are the following:

(a) Particle characterization,

(b) Surface and Colloid Chemistry,

(c) Dynamics of particle-liquid systems.

Complex solid-liquid separation phenomena frequently make the mathematical analysis dubious since slurries are notoriously fickle and change with time and treatment$^{(7)}$.

2.2.1 THE CONCEPT OF SEDIMENTATION IN THE SOLID-LIQUID SEPARATION PROCESSES.

Sedimentation is the separation of a solid phase from the liquid phase resulting from an external force (gravity settling) exceeding the magnitude of the frictional forces$^{(2,7,15,16,25)}$. It may be divided into two functional operations of thickening and clarification. The primary purpose of thickening is to increase the concentration of a relatively large quantity of suspended liquids in a feed stream. Clarification is to remove a relatively small quantity of fine suspended particles and to produce a clear effluent. Both these functions are related and the terminology merely makes a distinction between the process results desired. Gravity thickening requires much higher torques than clarification, and clarifiers frequently require the inclusion of flocculating devices to assist in the (coagulation or flocculation) clarification of dilute streams.

Complications arise in sedimentation depending upon the particle shape and size and the variable surface charges. The effects of other factors such as convection currents and particle-particle interactions are also evidenced$^{(7,25)}$. One simplification in the analysis of heterogeneous systems such as these encountered in water and waste-water treatment is to assume average properties and conditions for sedimentation.

Particle size, particle density and fluid viscosity are factors to be considered in any sedimentation process(15,16). Materials with particle diameters of the order of a few microns settle too slowly for most practical operations. Such particles may be agglomerated or flocculated into relatively large clumps which can settle out more rapidly.

The settling of discrete particulate masses based initially on the modifications of Stokes' law has featured in the researches of many workers with as many different solid-liquids systems(20,21).

Wallis(22) attempted to bring together the results obtained from a variety of conditions to categorize the behaviour of settling sediments of uniform particles greater than one-hundred microns sufficiently large for anomalous viscosity effects and flocculation to be regarded as negligible.

Four zones have been observed to develop during sedimentation(23,25). They were supernatant, suspension, sediment in compression and compacted sediment. Some authors preferred to break the compression zone into two and notably among these are Coe and Clevenger(24).

The overall process time depends on the type of settling aid used. Coagulants may give process times of several hours but certain acrylic-based polymer flocculants can achieve process times of a fraction of this(7,25). Process requirements and cost are therefore very important considerations in the selection of a settling-aid. Spherical and quite compact flocs can often be achieved by the application of a combination of electrolytes and polyelectrolytes. Such flocs are not only denser and faster settling but also entrain less of the suspending liquid and hence produce a more distinct separation.

2.2.1.1 FACTORS AFFECTING THE SEDIMENTATION PROCESS

The most important factors affecting the rate and the mode of settling of aqueous particulate suspensions are:

(a) the nature of the particles: size distribution, shape, specific gravity, chemical and mineralogical properties;

(b) the proportion of solids and liquid forming the suspension and concentration effects;

(c) the type of pretreatment: chemical conditioning and flocculation;

(d) the type of containing vessel: size shape and wall effects.

2.2.1.2 SETTLING CHARACTERISTICS OF SUSPENDED SOLIDS

Suspended solids found in industrial wastes vary appreciably in size, density and settling characteristics. Settling rates are also influenced by temperature and viscosity.

The settling characteristics of finer particles ranging from the micron to sub-micron size are impossible to predict. Laboratory test are necessary to determine settling characteristics(2,7,25).

Treatment of particles approaching micron size or less requires an understanding of colloid chemistry. Colloid stability depends on the forces of repulsion which exceed the forces of attraction. Properties of colloidal dispersions can be changed by changing particle size distribution by crystal growth, by comminution, by adding electrolytes or surface active agents.

Particle charge is distributed over two concentration layers of water surrounding a particle. These two layers are; an inner layer of water and ions which is tightly bound to the particle and moves with it through the solution, and an outer layer which is part of the bulk water phase and moves independently of the particle. Charges of these layers are not directly measurable but the zeta potential can be determined indirectly.

2.2.1.3 SELECTION OF THE SOLID-LIQUID SEPARATION PROCESS

The process of gravity sedimentation appears to be the most suitable to remove the solid fines from the colliery waste-water.

There are two methods of gravity sedimentation. Clarification refers to the removal of small quantities of particles which settle relatively independent of one another, with the production of a clear effluent with minimal solids. Thickening is the term used for more concentrated suspension in which particles undergo hindered settling with the production of a concentrated underflow.

From a comparison of these two methods clarification is the best method for the separation under consideration.

2.3 THE CLARIFICATION PROCESS

Clarification is often a two-stage process. The first stage is physico-chemical and it involves the conversion of discrete, unflocculated particles of the suspension into a thickened underflow with a clear overflow(25). This step is capable of a high degree of control, and is efficient, irrespective of the scale of operation. This reliability is, however, of vital importance in terms of establishing the conditions required for a similar effectiveness of the second stage.

The second stage, predominantly an engineering operation is to reduce the remaining water content by the transformation of the thickened fluid into a compact, rigid solid containing only small quantities of water.

It is widely recognized that whatever form of machinery which is chosen for the solid-liquid separation process of clarification the operation can be greatly facilitated by controlling the state of flocculation of the particles in the colloidal size range(19).

In clarification the suspended particles settle in different ways(7):

(a) Hydroseparation or Classification - Each particle settles separately and at its own rate.

(b) True clarification - Particles agglomerate into separated floccules which then settle out.

2.4 CHARACTERIZATION OF PARTICLES SUSPENDED IN LIQUIDS

Particles in suspended liquids are characterized into primary and secondary properties. The Primary properties are particle size distribution, shape, density, liquid viscosity and concentration, surface properties and the state of dispersion whilst the Secondary properties are the settling velocities of the particles, the permeability of the bed and the specific resistance of the cake(7). The primary properties govern the secondary properties.

As the relationships in solid-liquid separation are rather complex, the primary particle properties are mainly used for a qualitative assessment of the behaviour of the suspensions. The finer the particle size the more difficult is the separation and the concentration of the solids also plays an important role.

Characterization of solid particles, most of which are in practice irregular in shape, is usually made by analyzing the particle size and its distribution.

Small particles dispersed in a suspension are stabilized by forces due to the surface charges of the particles. For this reason, such particles do not agglomerate spontaneously. Most particles suspended in water such as clay, silica and hydrated metal oxides possess negative surface charges in the neutral pH range. Primary surface charges or suspended particles are produced by any of three distinct processes depending upon the composition of the solution and, on the nature of the solid phase(2).

One source of the surface charges is the imperfections in a crystal lattice. This source is responsible for a major portion of the charge on clay minerals(10,26). The sign and magnitude of charges produced by isomorphic replacements of individual atoms are independent of the characteristics of the aqueous phase. A second source of surface charges occuring on the particles is the variety of surface groups which are capable of ionization. The charge on these particles is dependent upon the extent of surface group ionization and on the pH of the solution. A third source of surface charges on suspended particles may arise from the preferential adsorption of certain ions from solution. The specific adsorption of these potential determining ions can arise from hydrogen bonding, covalent bonding or van der Waals bonding and can be augmented by electrostatic attraction (1,4,7,26).

Suspended particles are grouped into hydrophobic and hydrophilic classes. Particles classified as hydrophobic are not entirely water-repelling but only a few molecular layers of water are adsorbed at the solution-particle interface. Hydrophobic particles are stabilized in aqueous suspension principally by charge. They generally lack stability in the presence of electrolytes(1,7). Hydrophilic particles are actually slightly soluble macromolecules having a strong affinity for water due to the presence of polar groups which which retain sheaths of water around individual particles.

The various characteristics described above are further influenced by pH, temperature and concentrations of soluble salts in the suspending medium. The two most important characteristics of suspended particles to be considered relative to any separation process are the size and surface charge of the particles.

Many authors including Tiller(2) Svarovsky(7) Coulson and Richardson(15), Perry and Chilton(16) Allen(27) and Irani(28) have discussed the different techniques and applications in the measurement of particle size and distribution.

The size of a particle is that dimension which best characterizes its state of sub-division. Various methods of particle size measurement determine different measures of size and great care must be taken when making a selection as to what size is most controlled.

Conversion of size data developed from one set of particle properties to another can lead to significant errors and because of this, the particle sizing technique should duplicate the process under evaluation. Cole(29) used the Quantimet 720 to compare the longest chord, perimeter and the area for a large number of particles.

2.5 SURFACE CHEMISTRY APPLIED TO SOLID-LIQUID SEPARATION PROCESSES

Suspensions of fine particles in liquid media have properties which cannot be attributed solely to hydrodynamic factors. Such factors are:

(a) electrophoresis - migration of particles under the influence of an externally applied electric field,
(b) stability of suspension under certain conditions,
(c) dependence of stability on concentration(s) and type(s) of electrolyte(s) as well as on the nature of the solid,
(d) dependence of stability on pH
(e) agglomeration, coagulation, and flocculation,
(f) repeptization.

These phenomena have their origin in the special physico-chemical conditions that exist at regions in the intermediate neighbourhood of solid-liquid interfaces and the interaction between these regions. Such conditions exist at all solid-liquid interfaces but their presence becomes primarily important in solid-liquid suspensions due to the very large area per unit suspended mass(2,4). These phenomena affect profoundly all stages and facets of solid-liquid separation methods.

2.5.1 SURFACE CHEMISTRY OF COLLOIDS IN CONNECTION WITH STABILITY

The aggregation of colloids is known as coagulation or flocculation. Previously these two terms were used interchangeably but nowadays there is a trend to distinguish between aggregation due to simple ions as coagulation and aggregation due to polymers as flocculation.

Except under idealized laboratory conditions, colloid stability is a very complex matter. Several forces can be operative between colloids; some attractive and others are repulsive. These forces may react in different ways upon variations in the conditions such as pH, temperature and salt concentration(2,30). In order to understand which forces are operative, it is necessary to characterize these particles and especially the surfaces of these particles. Also to be considered is the rate at which the particle surface properties can alter relatively to the rate at which two particles approach each other(30). Both static and dynamic properties require attention. The treatmentof colloid stability is different for dilute and concentrated sols. In dilute sols aggregation is a bimolecular process and in concentrated systems all particles interact simultaneously with several neighbours.

Charges on dispersed particles are invariably due to an unequal distribution of ions over the particle and the surrounding solution. The particle charge and the charge in solution are equal in magnitude but opposite in sign(4).

The particle charge and the counter-charge together form an electrical double layer(2,4,7,10,26,30). The reason why an uneven charge distribution between particle and solution arises can be quite different depending on the nature of the particle(31,32,33,34).

In interfacial electrochemistry, it is customary to divide the double layer into three parts:

(a) surface layer

(b) Stern layer or molecular condenser which is defined as that part of the solution side that is close enough to the surface to be under the influence of specific effects stemming from the surface,

(c) a Gouy-layer or diffuse layer which is that part of the solution side that is far enough from the surface that specific effects may be neglected.

Tiller(2) Hunter(4) have discussed the theory of colloid stability which was developed almost simultaneously by Derjaguin and Landau in the U.S.S.R and Vervey and Overbeek in the Netherlands and this is called the DLVO theory of colloid stability which has also been discussed by many authors including Mackenzie(10) van Olphen(26) and Lyklema(30). The validity of this DLVO theory is limited to lyophobic colloids and simple electrolytes. The term stability when applied to colloidal dispersions is a relative term used to express the resistance of the dispersion with time.

The destabilization of colloidal dispersions can be accomplished by several different mechanisms. La Mer(35) has divided these mechanisms into the following categories:

(a) Process which cause a reduction of the total potential energy of interaction between the electrical double layers of two colloidals.

(b) Processes that aggregate colloidal particles into three-dimensional floc networks by the formation of chemical bridges.

La Mer(35) has designated the first category as coagulation and the second as flocculation. Stumm and O'Melia(36) pointed out that although certain well understood systems are easily classified according to these definitions the exact mechanisms of particle destabilization in water treatment are not completely classified.

Kuz'kin and Nebera(37) have discussed the degree and stability of numeral suspensions. The study of suspensions is not detached from colloids since in many respects their properties coincide with the properties of the finest dispersions. The following are properties common to both: the presence of a developed surface, of which the properties and the phenomena associated with these properties; determine the behaviour of suspensions; the presence of an electrokinetic and electrochemical potential at the phase interface; and hydration of particles. The stability of dispersed systems is one of the central problems in colloid chemistry.

Many authors including Tiller(2) and Hunter(4) have discussed the Schulze-Hardy rule on the critical coagulation concentration (C.C.C.). Addition of an adequate amount of coagulant to a given colloidal dispersion causes coagulation or flocculation. The minimum concentration above which coagulation or more precisely destabilization is produced, is denoted as the critical coagulation concentration.

The stability of lyophobic colloids can be achieved by one of the following methods(38).

(a) Adsorption of anions or of an anionic polyelectrolyte on the surface of the colloidal particle to create strong mutual repulsion due to high zeta potential;

(b) Adsorption of a strongly hydrated hydrophilic protective colloid on a layer hydrophobic colloid and this protective action is the most conspicuous influence of the addition of lyophilic colloids to lyophobic one,

(c) Adsorption of a non-ionic polymer of sufficient chain length to create steric hindrance to prevent two lyophobic particles from coming close enough to aggregate.

Colloid stability can be either increased or decreased by adsorbed polymers. If the polymer carries an opposite charge to the particles then the electrical repulsion is reduced and the particles can be destabilized. When the adsorbing material has the same sign of charge as the particles repulsion is increased and the particles are stabilized.

There are also many cases where colloidal stability can be significantly reduced by adsorbed non-ionic molecules and this is known as sensitization(26). This is usually related to a reduced surface charge brought about by the displacement of polar water molecules from the surface of particles in aqueous media.

2.5.2 THE ELECTRICAL DOUBLE LAYER-(THE IONIC DOUBLE LAYER)

The electrical double layer is often the most usual factor in deciding the stability of aqueous suspensions(37). Thus stability is the result of the electrostatic forces of repulsion which predominate over the attractive forces of the particles. Derjaguin and Landau(39) have developed a more exact theory. The theory of the electric double layer deals with the distribution of the counter-ions and the co-ions of a charged surface and with the magnitude of the electric potentials occuring in this region(40).

The ionic double layer was developed by Gouy(41,42), Chapman(43), Debye and Hückel(44) and this theory was improved by Stern(45) with the introduction of the concept of the Stern layer.

Gouy(41) and Chapman(43) independently developed the so-called diffuse double layer theory of plane interfaces. The principles which underlie the theory are very similar to those underlying the theory of strong electrolytes subsequently proposed by Debye and Hückel(44). Mathematically the Gouy-Chapman theory is the simpler since equations have been developed for planar rather than for spherical symetry.

Several refinements of the Stern theory have been suggested by many workers including Kruyt(46) and Sennett and Oliver(47); the most notable is that of Grahame(31). However, the Stern model, while it provides a rather simple picture of a complex phenomenon, mostly displays the properties of the double layer which have been deduced from experimental observations.

The ionic double layer has been treated theoretically by numerous authors including Tiller(2),Hunter(4),Svarosky (7), Coulson and Richardson(15),Shaw(40); Adam(49),and Ross(50) at various levels of detail. Most treatments rest upon the theories of Gouy and Chapman and of Stern. These two theories are complementary. Stern modified the Gouy-Chapman model in order to bring it more into line with reality.

Hunter(4) has discussed the potential and charge in the electrical double layer for the various geometries of a flat disc sphere and cylinder.

2.5.3 MODIFICATIONS TO THE GOUY-CHAPMAN THEORY

Several assumptions were made in the analysis of the double layer according to the Gouy(41) and Chapman(43) models. These assumptions are:

(a) the charge on the solid surface is considered to be uniformly distributed,

(b) the ions which make up the diffuse layer are considered to be point charges,

(c) the solvent is a structure-less medium whose only influence is through its dielectric constant.

Stern recognised the assumptions that the electrolyte ions could be regarded as point charges and the solvent as a structure-less medium of dielectric of constant permittivity were unsatisfactory. This effect is most obvious experimentally when the measured values of the electrical capacitance of an interface are compared with theoretically calculated values(4).

Aveyard and Haydon(48) have also discussed three of the important shortcomings in the application of the Gouy-Chapman diffuse double layer theory. These authors have also discussed the Stern theory and the molecular capacitor in the ionic double layer. The dielectric constant in the Stern layer is well below that of the bulk solution.

Graham(31) has attempted to modify the Gouy-Chapman and Stern theories by taking into account that, in the Stern layer there may be two types of ions; one of which is specifically adsorbed, the other being merely a normal hydrated ion at its distance of closest approach to the surface. The specifically adsorbed ion is assumed to lose some of its water of hydration and to be closer to the surface than the other ion.

In current theories of the double layer the problem is alleviated by dividing the space charge in the electrolyte solution into two regions: the compact or the inner region is near to the wall in which the charge and potential distribution are determined chiefly by the geometrical restriction of ion and molecule size and short range interactions between ions, the wall and adjoining dipoles. Also the diffuse layer is further out from the wall where the Poisson-Boltzmann equation may be expected to give a reasonable representation of the potential distribution.

The dielectric permittivity has been found to vary over the compact or inner layer by many authors including Hunter(4) and Aveyard and Haydon(48).

The significance of the discreteness of the charge effect was first recognized by Frumkin(51) and the first calculations of its magnitude were made by Esin and Shikov(52). The importance of the discreteness of charge effect is that it appears to be able to explain a wide variety of effects which are not explicable using the simple version of the Gouy-Chapman and Stern theories.

The calculation of the discreteness effect has been fully reviewed by MacDonald and Barlow(53), Levine et al(54) and more briefly by Levine(55).

2.6 THE ELECTROKINETIC PHENOMENA

An electrical double layer is set up at almost every phase boundary and associated with this double layer there is a charge in electrical potential. A practical way to characterize the double layer is to measure the zeta potential and several techniques(4,7,10,40) are available. If two phases originally uncharged are brought into contact, one phase assumes a slight positive charge and the other an equal negative charge(49).

In any system which contains matter in two phases with different charges, the application of an electric field causes one phase to move relatively to the other. The negatively charged phase moves towards the positive pole and the positively charged phase towards the negative pole. This motion is called the electrokinetic movement(2,4,7,10,11, 40,48,49,50). The rate of relative motion of the two phases is proportional to the intensity of the applied field. It also depends on the size and shape of the particulate matter, on the properties of the fluid, and on the structure of the double layer particularly on a certain potential called the electrokinetic or zeta potential.

Electrokinetic phenomena include four distinct processes namely electrophoresis electro-osmosis, streaming and sedimentation potential.

Overbeek(9,12) and others have reviewed an outline of the principles of electrokinetic phenomena including the practical difficulties of measurement.

The electrokinetic velocity is measurable and unambiguous. The electrokinetic or zeta potential which is deduced from the electrokinetic velocity is defined as the potential at the plane of shear of liquid(4,10,40,48). It is necessary to know the position of the plane of shear in order to attach significance to the zeta potential and to relate it to the structure of the double layer. Herein lies the principal difficulty in the interpretation of the electrokinetic data especially when the double layers are subject to shearing forces(11). The electrokinetic problem can be examined in two parts. Firstly, the conversion of the electrophoretic mobility into zeta potential. Secondly is the difficulty in trying to decide where the position of the slipping plane is located. These two problems are interrelated unless the viscosity in the continuous liquid phase is constant or has a very large and abrupt discontinuity. Owing to a lack of knowledge concerning the viscosity of solutions near the surfaces the hydrodynamic equations have, until recently, only been solved for constant viscosity in the liquid phase.

2.6.1 DIRECT APPLICATIONS OF ELECTROKINETIC PHENOMENA

Any process which involved the separation of particles with the difference in zeta potential suggests itself as suitable for an electrokinetic separation technique.

In the field of lyophilic colloids the electrophoretic separation of proteins and amino acids is common place. There does not appear to have been much application in the separation of lyophobic colloids probably because separations are more easily accomplished by other methods. Electrophoretic deposition has been applied in several cases(4,10.11.26).

Ross(50) has reviewed a recent study by Todd and Wild which described a unique separation procedure which is related in some way to the electrical character of a solid-liquid interface. This separation procedure was applied to mineral particles in the range of one to thirty microns and suspended in non-conducting organic liquids.

Many authors(4,10,26) have investigated electrophoresis and the liquid counterflow (electro-osmosis) as a means of dewatering fine particle size suspension which are amenable to filtration.

The zeta potential is closely connected with the stability of lyophobic colloids. If it is reduced below a critical value the dispersed particles coagulate or flocculate rapidly. Ions of opposite charge to the colloidal particles are easily adsorbed and cause coagulation or flocculation. The effectiveness of the ions increases enormously with increase in valency according to the well-known Schulze-Hardy rule.

2.6.2 THE ZETA POTENTIAL-MOBILITY RELATIONSHIP FOR CONSTANT DIELECTRIC CONSTANT AND VISCOSITY

Of the various forms of electrokinetic phenomena, particular reference will be made to electrophoresis. Many authors including Hunter(4) Mackenzie(10) Shaw(40) Overbeek(56) and Booth(57) have reviewed the details of derivations and theory on electrophoresis.

One of the most commonly applicable forms of zeta potential-mobility relationships have been derived by Smoluchowski(58). Henry(59) has deduced an equation based on a number of simplifying assumptions. Overbeek(9) has improved Henry's result by introducing the relaxation correction. This makes an allowance for the deformation by the external field of the space charge and potential distributions near the particle and for ionic diffusion. Overbeek also attempted to avoid the linear approximation of the Poisson-Boltzmann equation. The neglect of Brownian motion has been shown by Overbeek(56) to be justified provided the colloidal particle is at least ten times the size of the electrolyte ions.

Haydon(11) has reviewed the influence on the mobility of a non-uniform conductance of the particle which has been investigated independently by Booth(57) and Henry(59). The special interest and importance of this problem is that the conductance in the surface phase near a particle may be considerably higher than that in the bulk of the solution. Pickard(60) has re-examined the basis of electrophoretic equations and has made several critisms of Overbeek(56) and Booth(57).

2.6.3 THE ZETA POTENTIAL-MOBILITY RELATIONSHIPS AND THE VARIATION OF DIELECTRIC CONSTANT AND VISCOSITY IN THE DIFFUSE LAYER.

The supposition that the ratio of viscosity to dielectric constant is constant and equal to the value in the bulk phase is probably unjustified(11,61,62). To show conclusively that this is true is rather difficult. Neither viscosity nor dielectric constant in the double layer has been measured directly. Estimates have to be made from a knowledge of the double layer structure at a selected surface. For such a system it is sometimes possible to derive from the known surface charge or from other sources, the value of the potential at the physical boundary between a solid and liquid(11). This potential can then be compared with the zeta potential calculated on the assumption of a bulk value of the ratio of the viscosity to the dielectric constant.

To deduce whether the diffuse layer dielectric constant or the viscosity is responsible for the high values of the ratio of the viscosity to the dielectric constant in the diffuse layer is difficult. Evidently this can be caused by a large viscosity or a small dielectric constant both of which are possible at high field strengths. There appears to be no data on the effect of high fields on the viscosity of water and viscoelectric constant for water. A theoretical estimate of the viscoelectric constant has been carried out by Lyklema and Overbeek(61). The main effect of the analysis is to replace the older concept of a well-defined slipping plane by a slipping layer in which the viscosity varies continuously.

2.6.4 THE VARIABILITY OF THE DIELECTRIC CONSTANT AND VISCOSITY IN THE ELECTRICAL DOUBLE LAYER

Electrokinetic measurements are of considerable interest for the study of the electrical double layers. Such measurements are difficult to interpret and have been frequently criticized by many authors including Hunter(4,62) Haydon(11) and Lyklema and Overbeek(61) on two counts. These were:

(i) the failure to take account of the variations in the viscosity and dielectric constant owing to the high field strength in the immediate neighbourhood of the particles,

(ii) the uncertainity in the position of the plane of shear.

Levine et al(54) have criticized the theory on which Haydon(11) based his calculation of the surface potential. Whether it influences the relation between the zeta potential and electrophoretic mobility depends on the actual value of the dielectric constant in the outer region of the double layer. The justification in the use of the bulk value of the dielectric constant in the electrophoretic equation by Helmholtz and Smoluchowski was inferred by Lyklema and Overbeek(61). Hunter(62) has reviewed the variation of permittivity with field strengths; the relation between the zeta potential and "Smoluchowski" zeta potential for variable permittivity but constant viscosity and the influence of surface charge density on position of shear plane.

2.6.5 THE APPLICATIONS OF MICRO-ELECTROPHORESIS

Electrophoresis is by far the most common procedure for determining the zeta potential and a large number of different techniques have been developed for the application to different kinds of material(4,10,26,40). The most important is the micro-electrophoretic procedure in which the movement of individual particles under the influence of a known field is followed directly in an ultramicroscope assembly or dark-field microscope.

The applications of micro-electrophoresis fall largely into two classes. Firstly, is the determination of zeta potential for the purposes of interpreting colloid stabilities.

To apply this approach it is customary to identify the zeta potential with the potential in the outer Helmholtz plane and to assume this potential to be the operative potential in controlling the electrostatic forces between particles (4,10,11). Recently techniques(63,64,65,66) have been developed which enable zeta potentials to be measured in media of low dielectric constant where the low ionic concentrations can nevertheless cause large surface potentials. It is imperative to have reliable zeta potential-mobility relations for all potentials and the shape factor values and to comprehend the problem of viscosity variations.

The second application is the investigation of the nature of particle surfaces, and the greatest interest is usually in the nature and magnitude of the surface charge.

Tiller(2) Svarovsky(7) Mackenzie(10), Kitchener(19) and van Olphen(26) and Shaw(40) have also discussed the various applications of micro-electrophoresis.

2.6.6 THE ELECTROKINETICS OF CLAY-WATER SYSTEMS

Electrical properties of clay-water systems are determined principally by the structure of the electrical double layers on the clay surface. Although the negative-face double layer probably plays the major part, possible contributions of the edge double layer should not be overlooked in the interpretation of electrochemical and electrokinetic behaviour of the clay-water systems(26). The electrochemistry and electrokinetics of dispersed systems have been a subject of considerable confusion and controversy(1). The significance of the zeta potential as a quantitative stability criterion has often been overestimated and its computation from the electrokinetic data has been oversimplified(4,26,37).

Considerable difference of opinion has prevailed in the interpretation of electrochemical-potential measurements on clay suspensions and on clay membranes or shales.

Electrokinetics and electrochemistry of dispersed systems are difficult subjects which do not readily lend themselves to elementary treatment. For clay surfaces the charge density is independent of the electrolyte concentration.

The effect of cationic valency is very strong, and divalent ions could reduce the charge to zero at low concentrations while trivalent and tetravalent ions could cause a reversal(67).

Both in natural waters and in industry, deliberately added ionic surface active substances may adsorb on particles and thus charge them(1).

2.6.7 THE ELECTROKINETICS OF COAL SUSPENSIONS

Information regarding the detailed electrokinetic studies on coal is still lacking and research on the subject is at an early stage of development(68).

Baker and Miller(69) indicated the importance of zeta potential control in coal preparation for plants such as thickening, clarification and froth flotation. It has been observed in filtration rate studies of coal slurries that the flocculant efficiency improves as the zeta potential approaches zero.

Hydrogen and hydroxyl ions appear to be responsible for the charge on the surface of coal. These ions participate in the charge distribution which leads to equilibrium at the coal-water interface(70). By determining the electrophoretic mobilities of the fine coal particles as a function of pH, the iso-electric points of various coals were found to correspond to the pH at which the mobility is zero(70).

Brown(71) has suggested that the mechanism by which the zeta potential of coal varies with increasing acidity of the solution. Hydrogen ions are preferrentially adsorbed in the electrical double layer on the surfaces of coal and this results in the lowering of the negative surface charge of coal. With subsequent addition of hydrochloric acid the negative charge on the surface is reduced to zero and the iso-electric point is reached. Any further addition of hydrochloric acid makes the surface charge positive. In alkaline solutions, hydroxyl ions are adsorbed in the diffuse part of the electrical double layer at the coal-water interface. Consequently the magnitude of the negative zeta potential is increased.

Campbell and Sun(68) found that the iso-electric point of anthracites occured in acid solution between the pH 2.5 and 5.0. These authors also found that durains and fusains in anthracite yielded much higher iso-electric points than vitrains in anthracite or whole coals in general. In their opinion this shift is undoubtedly an effect of the higher mineral content in the durains and fusains and the zeta potential variation with pH for whole coals is a result of the combined effects of the various lithotypes.

2.7 FLOCCULATION

The tendency of the particulate phase of colloidal dispersions to aggregate is an important physical property which finds practical application in solid-liquid separation processes(72). The essential steps in the flocculation of suspensions are:

(a) Destabilization of the particles by the elimination of any repulsion between them.

(b) Collisions of destabilized particles to form aggregates or flocs.

Flocculants are added to the pulp prior to thickening with the objective of increasing the settling rate of the pulp solids, hence increasing the thickener capacity and decreasing the overflow density(73). Flocculant additions are beneficial where the pulps contain appreciable quantities of finely divided clays which will not otherwise settle. Under these conditions the addition of flocculants may be economically justified by the improved operating conditions which may result from the circulation of a low solid content overflow and by the avoidance of stream pollution.

These benefits have been discussed in detail by Dahlstrom(74) and Matoney(75).

The two main problems associated with the use of flocculants in washery circuits are the selection of effective and economical flocculants from the wide range of reagents available and the prediction from laboratory experiments of the quantity of flocculant required for plant operation.
A possible treatment is selective flocculation by means of which one component can be caused to aggregate and thus become more readily separable. According to the accepted theory of colloid stability small particles are attracted to one another by van der Waals forces and tend to aggregate unless they are kept apart by repulsive forces arising from the presence of the electrical double layer(73).

Coagulation and flocculation processes can and do occur simultaneously or with some degree of overlapping. They are distinguished by their mechanisms of destabilization, the types of chemicals used for their initiation and the sizes of particles developed.

Coagulation is defined as the conversion of colloidal and dispersed particles into small visible flocs upon the addition of a simple electrolyte. Increasing the concentration of the electrolyte compresses the electrical double layer surrounding each suspended particle and decreases the magnitude of the repulsive interactions between particles thereby destabilizing the particles.

Flocculation is the further agglomeration by an organic polyelectrolyte. Polyelectrolyte flocculants are linear or branched organic polymers. They have high molecular weights and are water soluble.

Certain insoluble particulate materials which are designated as coagulant or flocculant aids are often added to suspensions to enhance solid-liquid separation.

Hydrodynamic aspects of flocculation have been discussed by Spielman(77). Gregory(38) has also reviewed the flocculation by inorganic salts and the effects of polymers on colloid stability. There are many cases where colloid stability can be significantly reduced by adsorbed non-ionic molecules. This is known as sensitization and is concerned with a reduced surface charge. Sontheimer(78), has discussed flocculation in water treatment. O'Melia(36) has reviewed the coagulation processes in waste-water treatment.

The role of surface silanol groups in the flocculation of silica suspension by polyacrylamide has been carried out Griot and Kitchener(79). Flocculation by water-soluble polymers has been reviewed by Kitchener(80). Electrokinetic, adsorption and subsidence studies on quartz dispersion in the presence of a commercial synthetic polyacrylamide type flocculant have been reported by Healy(81).

Linke and Booth(82) have reviewed the physico – chemical aspect of flocculation by polymers. This involved a broad general study of the physical chemistry of mineral-polymer systems and the application of **better** polymeric flocculants and dispersants for the mining industry.

Dixon et al(83) have investigated the application of cationic polymers.

The characteristics of flocculation of mineral suspensions by polymers have been reviewed by Slater and Kitchener(84). In many coal cleaning operations it is usual to add flocculants to the coal concentrates prior to filtration to increase the filtration rate(85).

The effect of a number of variables on the coagulation of dilute clay suspensions with aluminium and iron coagulants was investigated by Packham (86). The variables included the nature and concentration of clay, pH and the presence of different ions.

A quantitative theory was presented which described the kinetics of coagulation of colloidal systems containing more than one dispersed species(87). Using the linear Debye

Hückel approximation for low surface potentials a general expression has been derived to describe the potential energy of interaction between dissimilar spherical colloidal particles.

Studies on the mechanism and the rate of coagulation of positive silver iodide sols by anionic surface active agents have been investigated(88). The electrophoretic behaviour of positive silver iodide sols in the presence of anionic surface active agents has been studied by Ottewill and Watanabe(89).

Kuz'kin and Nebera(37) have reviewed extensively the synthetic flocculants used in dewatering processes.

Akers(90) has reviewed the destabilization of suspensions by coagulation and flocculation.

2.7.1 THE APPLICATION OF ZETA-POTENTIAL DATA TO FLOCCULATION STUDIES

Flocculation of mineral suspensions by polymeric reagents is considered to result from a bridging mechanism (81,82,91) in which the effect of the electrical double layer interactions is minor. The study of the bridging mechanism is not readily amenable to investigation by electrokinetic techniques. The absorption of charged polymeric species to charged mineral surfaces will produce changes in the zeta potential(10).

Healy(81) and Kuz'kin et al(92) have applied the zeta potential measurements to study the adsorption of polymer flocculants to minerals such as quartz, microlite calcite and fluorspar. Healy(81) considered that although the adsorption of a partly hydrolyzed polyacrylamide reduced the zeta potential of quartz, this reduction of zeta potential was subsidiary to the bridging mechanism in causing aggregation and flocculation. Kuz'kin et al(92) in the study of the relationships between the zeta potential, polymer adsorption and flocculation showed that the adsorption and the bridging mechanism were influenced by the surface charge and the charge on the polymer chain.

Matheson and Mackenzie(85), Kuz'kin et al(92) and Slater(93) have shown that polymer flocculation of negatively charged minerals by anionic polymers can be activated by the presence of divalent metal cations.

Dixon et al(83) have studied the effect of cationic polymer adsorption on the stability of silica and concluded that low-molecular weight cationic polymers can cause coagulation of silica, which brings the particles sufficiently close together for short-range hydrogen-bonding forces to promote bridging and flocculation. They suggested that highly hydrated oxides of iron and aluminium may function as flocculants for silica in the same manner as the low-molecular weight cationic polymers.

Black et al(94) have investigated the effect of cationic polymer adsorption on the stability and electrophoretic mobility of kaolinite and montmorrilonite suspensions. Their results demonstrate a close relationships between zero zeta potential and minimum residual turbidity and also provide electrokinetic evidence for the restabilization which takes place when the particle surface becomes saturated with polymer molecules.

Kuz'kin et al(37) have studied the effects of weakly anionic polymers on both zeta potential and flocculation of silica and showed that the maximum degree of flocculation occured at conditions of low zeta potential. Whether there is any direct relationship between the zeta potential reduction produced on negative surfaces by anionic polymer adsorption and the flocculation produced by adsorption remains uncertain.

2.7.2 THE APPLICATION OF ZETA-POTENTIAL STUDIES TO COAGULATION OF MINERAL SUSPENSIONS

The coagulation of mineral suspensions by simple electrolytes is more suited to the quantitative use of the zeta potential data than most other mineral processing operations. The Derjaguin-Landau(95)- Vervey-Overbeek(96) (DLVO) theory requires for its application the numerical values of the Hamaker constants and of the Stern potential. Unfortunately direct measurement of the Stern potential is not possible for most systems.

Many of the applications of the DLVO theory to the mineral processing coagulation systems have been concerned with suspensions of silver iodide, silica and polystyrene. The particle sizes were very small and the suspensions acted as Rayleigh scatterers which facilitated measurement of turbidity.

One of the disadvantages of this approach has been that these suspensions exhibit surfaces which may not be similar to those of the strongly crystalline comparatively coarse particles in mineral processing operations.

A number of investigators including Mackenzie(10) have developed models for coagulation of suspensions using hydrolysable metal cations which involve a combination of coagulation and flocculation mechanisms. These models have been developed because some of the coagulation data for regatively charged suspensions in the presence of hydrolysable cations cannot be interpreted in the terms of the DLVO theory.

Several theories have been proposed to explain the coagulating behaviour of hydrolysable cations. This included heterocoagulation of positively charged metal hydroxide precipitate and negatively charged suspension particles, and flocculation via polymer bridges of the solution by polymeric uncharged hydrolysis products(89,90). It is not possible to determine which of these mechanisms control the coagulation and flocculation of suspensions by hydrolysable metal ions. The apparent lack of correlation between zeta potential data and coagulation data for these systems would suggest that electrokinetic techniques are of little value in studying coagulation. However it is this lack of correlation which has led many workers(4,10,26) to search for other coagulation mechanisms, thereby justifying the initial application of zeta potential measurements.

These measurements have also aided in the determination of species which adsorb at mineral-water interface. Hence despite the failure of the DLVO theory for certain cases of combined coagulation-flocculation processes, the value of zeta potential measurements in understanding these processes is considerable(4,10).

2.7.3 ZETA POTENTIAL STUDIES ON THE ADSORPTION OF METAL CATIONS AT THE MINERAL-WATER INTERFACE

The adsorption of metal cations at the surface of mineral particles has been the subject of extensive electrokinetic studies by a number of workers including Healey et al(97), Mackenzie(98), Mackenzie and O'Brien(99) and Hall(100). Others including Clark and Cooke(101) have studied the action of metal cations as flotation activators for quartz in the presence of anionic collectors. Matijevic and co-workers (102,103,104) have studied the action of metal cations as coagulants for non-mineral sols such as colloidal silica. They discussed their results in terms of electrophoretic mobilities.

The results of these investigations demonstrate that the metal hydroxy cation species are far more effective than the simple metal ion in causing reversal of the zeta potential, coagulation of oppositely charged suspension and flotation activation.

The adsorption of metal cations to mineral surfaces is a phenomenon which while amenable to zeta potential measurements, must be studied by other complementary techniques such as adsorption studies or flotation if meaningful interpretations are to be made of the zeta potential data(10). However it is partly as a result of zeta potential measurements that this phenomenon has been capable of physico-chemical interpretation.

2.7.4 THE APPLICATION OF ZETA POTENTIAL DATA TO THE STUDY OF SELECTIVE AGGLOMERATION PROCESSES

Selective - agglomeration concentration processes are those in which selective agglomeration of a particular mineral followed by the separation of the agglomerates from the dispersed minerals. This method is used to effect the concentration of the desired mineral. The processes vary widely in their technology and include operations such as "piggy-back" flotation, emulsion flotation and selective flotation(10,93).

One aspect which is common to these processes is that it involves the concentration of extremely fine-sized mineral particles which are too fine to be concentrated by other processes such as flotation.

Shergold and Mellgren(105) used electrokinetic data to study the mineral-water interface reactions involved in emulsion flotation and established a relationship between the point of zero charge of the mineral and flotation recovery.

Yarrar and Kitchener(76) have made extensive use of zeta potential measurements in their analysis of the selective flocculation process and have shown that for synthetic mixtures, a knowledge of the appropriate zeta potential, and the effect of pH on these potentials could provide a basis for predicting the conditions for separation.

Sun and co-workers(106,107) have studied the electrokinetic properties of anthracite and bituminous coal. They postulated that the coal surface hydrates and then undergoes pH-controlled dissociation to establish a charged surface in the same manner as the oxide minerals(13). The authors pointed out that, in view of the heterogeneity of the coal surface it is impossible to be certain how much the electrokinetic data reflect the properties of the coal or mineral matter surface.

2.8 CONCLUSION

In the past the mineral industry has been seriously hindered by the awkward colloidal minerals and where water and space were readily available, the slimes were dumped into rivers and settling lagoons. If the concentrates or clay products had to be dried the operation had to be carried out at a reasonable cost. The situation is now changing rapidly and a number of factors such as falling grades, environmental protection and rising fuel cost will have to be taken into consideration.

It is widely recognized that whatever form of machinery is selected for the solid-liquid separation process, the operation can be greatly facilitated by controlling the flocculation of the particles in the colloidal range.

In the first half of this century mineral technology was successfully carried forward by ad hoc inventions. There is now a need for continuing research effort into the science of colloidal minerals so that improved technologies could be rationally developed to treat smaller particles in environmentally acceptable terms.

The surface chemistry of mineral grains in water should be understandable in terms of the dissolution and surface ionization of idealized compounds. In practice due allowance must be made for non-equilibrium conditions and time effects, the effect of impurity elements, degradative changes of the mineral and reactions with substances deliberately present in the aqueous medium(19). These chemical factors can generally be manipulated to permit dispersion, separations, coagulation, flocculation and flotation.

For a thorough description of the progress of aggregation it would ideally be desirable to have a record of the initial particle size distribution and composition as a function of time(2,19,27,37). None of the classical techniques for measuring coagulation and flocculation such as turbidity, particle counting and light scattering offers a quantitative measure of a concentrated slurry containing a wide range of particle size. Consequently experimenters are obliged to devise empirical test methods to suit their particular objectives without being able to extract fundamental data from the results(2,17,19).

A number of complications may arise because mineral slurries commonly contain particles of different sizes and shape and also mineral species of different chemical nature. Hence the effects of heterogeneity can be anticipated in addition to the distinct perikinetic and orthokinetic flocculation mechanisms.

Before the advent of synthetic polymeric flocculants waste mineral slimes were dumped in a slimes dam usually with an addition of lime to precipitate out heavy metal salts and to encourage coagulation and flocculation. Inorganic coagulants such as alum and ferric salts were never extensively applied for mineral slimes because of their lack of strength to bond relatively large particles unless used at very large dosages.

The first use of organic flocculants appears to have been the use of starch together with lime for the clarification of colliery effluent containing coal particles with clay from the shale(19,37). Regrettably it is still not possible to select the best flocculant for a particular ore entirely on physical principles(2,17,19,37). The simple idea of choosing a polyelectrolyte of opposite sign to that of the solids rarely gives the best results, either in terms of floc size or reagent cost, though more or less effective flocculation can always be guaranteed on this basis. Knowledge of the zeta potential of the particles and its dependence on the ions in the medium is desirable together with possible interaction of these ions with the flocculant.

As most minerals in waters carry a moderate negative zeta potential the most useful flocculants are the very high molecular weight polyacrylamides incorporating a minor proportion of carboxyl groups to obtain expansion. It is advantageous to reduce the zeta potential of the particles considerably before or after the addition of the flocculants either with divalent or hydrolyzing cations or polyamine type of primary coagulants(2,19,37,90). In most cases there will be many possible answers to a given flocculation problem. The best will not necessarily be the cheapest flocculant that works or the one which gives the largest flocs, the clearest supernatant or the fastest filtration. Every situation should be optimized on its merits depending on the relative importance of the various factors.

Flotation is presently widely used to recover the fine coal particles. The waste slurries contain mainly shale particles. Much of the water should be recycled but if the solids build up beyond fifty grams per litre flotation grade suffers because of slime coating. At one time starch products were used to aid the solid-liquid separation but they have been largely displaced by polyacrylamides. In addition to the water problem there is need to improve the thickening and filtration of the suspended solids so as to get these wastes into sufficiently solid form for transport and dumping. The plant needs control to ensure that free polymer does not get back to the flotation unit where it can act as a depressant. In contrast to relatively amenable shale suspensions there are certain clay slurries which present much greater difficulties (19,26).

In current mineral processing research there is the need to develop new technologies for recovering valuable minerals from slimes since these slimes rejected from the conventional flotation plants often contain in substantial proportions of the valuable minerals.

Several distinctly different principles have been proposed for effecting mineral separation in the colloidal size range and many combinations of processes are possible(108).

The physico-chemical methods of separating mineral particles are economically attractive down to a tenth of a micron size since the amount of the chemical reagent required to modify the surface chemistry is still small compared with the amount of the reagents needed to dissolve the valuable constituents of the ore and to carry out a purely chemical separation.

It can be concluded that both flocculation and selective flocculation have proved practicable and adaptable to a variety of problems including clarification of colliery waste-water. It is not too costly but reliable economic estimates can be made only for specific cases after thorough bench and pilot-plant testing(2,7,19,37).

PHYSICO-CHEMICAL PROPERTIES OF COLLIERY WASTE-WATER

CHAPTER 3

3.1 INTRODUCTION

The colliery waste-water was obtained from the South Celynen Coal Mines at Newbridge, Gwent in South Wales. It was taken at the point before the colliery waste-water was sent to the flocculation unit. The colour of the colliery waste-water is light to dark brown, containing black and brownish-black particles.

Coal is a combustible solid usually stratified which originates from the accumulation and burial of partially decomposed vegetation in previous geologic ages. There is a wide range in the composition and the physical and chemical properties of different kinds of coal.

Coal lumps are black or brownish-black in colour. The colour, lustre, texture and fracture vary with type, rank and grade. The composition of coal is chiefly carbon, hydrogen, and oxygen with minor amounts of nitrogen and sulphur together with varying amounts of moisture and mineral impurities. The composition depends on the degree of alteration of the original plant ingredients, on their subsequent upgrading in rank and pressure and temperature effects in the earth and on mineral impurities deposited in the original bog. It is thought that the predominant organic components have resulted from the formation and condensation of polynuclear carboxylic and heterocyclic ring compounds containing carbon, hydrogen, oxygen, nitrogen and sulphur(109).

The mineral constituents in coal may be the residue of mineral substances present in the original plants, detrital minerals deposited at the time of formation, or secondary minerals crystallized from waters percolating through the coal seams. The most common detrital material is clay and it may be associated with quartz, feldspar, muscovite, rutile and topaz. The secondary minerals are generally kaolinite, calcite and pyrite. Traces of other elements such as vanadium, titanium, manganese and calcium have been found in coal ash and are thought to represent the minerals surviving from the plant material(26,67,109).

Clays are usually composed of one or more clay-minerals. These minerals include hydrous silicates of aluminium, iron or manganese with or without other rock and mineral particles. Clay may originate through several processes such as hydrolysis and hydration of a silicate, solution of a limestone or other soluble rock which contains relatively insoluble clay impurities that are left behind(26,109). Clays are characterised by fine particles of colloidal size and by wide variations in physical and thermal properties and in mineral and chemical composition.

Clay is used by geologists as a size term which refers to sediments or sedimentary rock particles of mechanical deposition. Soil scientists also define clay as disperse systems of colloidal products of weathering in which secondary mineral particles of smaller dimensions predominate. Ceramists usually colour their definition by emphasizing plasticity and its alumino-silicate content. Clay minerals are considered as degradation products of silicates which may be built up from hydrates of silica and alumina(109). Clay deposits usually contain more or less non-clay minerals as impurities. These may be beneficial and critically necessary to give clay its unique and specially desired properties.

The mineralogy of clay minerals rested on a poorly organized and insecure foundation until satisfactory apparatus and techniques, especially x-ray spectroscopy were developed to study the fine mineral particles. Crystalline clay minerals are identified and classified primarily on the basis of crystal structure and the amount and locations of deficit or excess charge with respect to the basic lattice (26,109,110).

Various techniques are used to study crystalline clay minerals including electron micrographs, transmission electron micrographs, scanning electron microscopy, x-ray or electron power diffraction and differential thermal analysis(26,109,110,111).

The clays of different groups are chemically similar but they show vastly different mineralogical, physical, thermal and technological properties(26,110). Chemical analysis alone may have limited values in revealing the clay's identity or usefulness.

3.2 THE PHYSICAL PROPERTIES OF THE COLLIERY WASTE-WATER

The densities of the raw waste-water, the suspension obtained after twelve hours of sedimentation and the filtrate obtained after filtration of the suspension were determined.

The weight of the sediment in the colliery waste-water was also determined.

Samples were allowed to settle for twelve hours to obtain a sediment and a suspension. The suspension was decanted, weighed and its volume measured. This suspension was then filtered using Millipore membrane filters (porosity of 0.22µm) to determine the amount of solid fines in suspension. Twelve experiments were carried out.

The density at ambient temperature of the raw colliery waste-water was found to be between 972.6 kg/m^3 and 1008 kg/m^3; the density of suspension obtained after twelve hours of sedimentation 950.1 kg/m^3 and 989.1 kg/m^3; and the density of the filtrate obtained after the filtration of the suspension 940.4 kg/m^3 and 993.4 kg/m^3.

The amount of sediment obtained after twelve hours of settling and the decantation of suspension above the sediment was determined to be between 3.1% and 3.6%.

Detailed results will be found in Appendix A1.

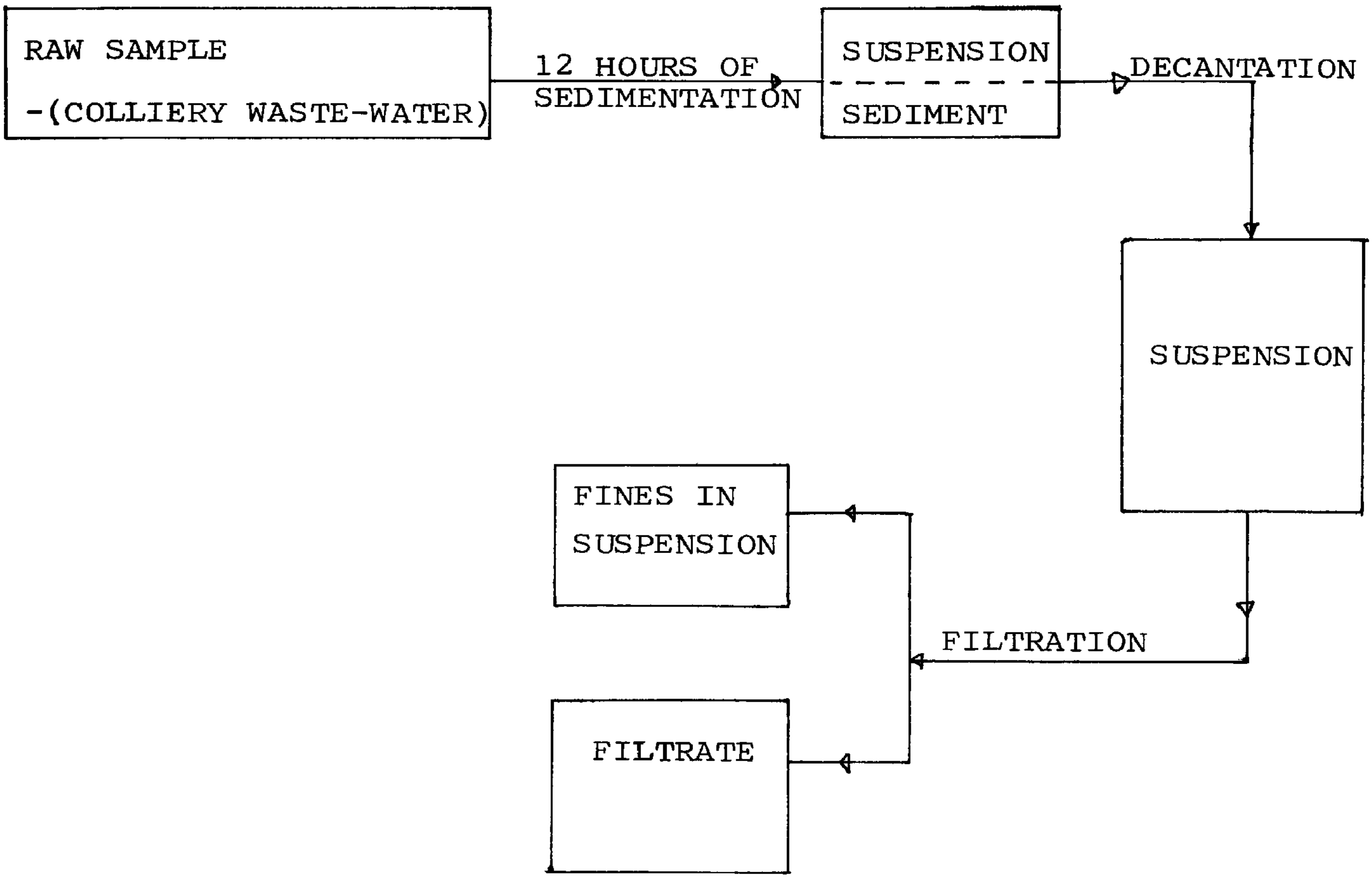


Fig. 3.1 DETERMINATION OF THE DENSITIES OF RAW COLLIERY WASTE-WATER, SUSPENSION, FILTRATE AND THE AMOUNTS OF SOLIDS IN THE SEDIMENT AND SUSPENSION.

3.3. THE PARTICLE SIZE MEASUREMENT

Characterisation of the particle size distribution is one of the most basic physical properties common to finely divided substances.

Particle size distribution covers the quantitative determination of the various substances in the sample down to the fine grain size as reported in BS.1377:1975, paragraph 2.7.

Many authors including Tiller(2) Svarovsky(7) Coulson and Richardson(15), Perry(16), Allen(27) and Irani et al(28) have investigated and reviewed particle characterisation size and distribution which include the methods of optical microscopy, scanning electron-microscopy and the electrical sensing zone method (Coulter Counter).

3.3.1 OPTICAL MICROSCOPY IN PARTICLE SIZE MEASUREMENT

Microscopy is the most direct method for particle size distribution measurement. Its range of application is very large but practical limitations and availability of more expedient techniques make microscopy a less desirable tool in certain size ranges. Microscopy is an absolute method of particle size analysis since it is the only method in which the individual particles are observed and measured. It also permits the examination of shape.

The Greenough Binocular Stereoscopic microscope-Olympus Model X and the Vickers M14/2 Patent No. 877813 microscopes were used to observe the particles.

The raw colliery waste-water was observed to contain fines (fine solids) of various sizes and their shapes were irregular. They were observed to be light to dark-brown and greyish-black and some of the particles were highly reflecting. In some cases, some of the light reflecting particles were enclosed in a dark brown or greyish matrix.

3.3.2 SCANNING ELECTRON MICROSCOPY (S.E.M.) IN PARTICLE SIZE MEASUREMENT

In the scanning electron microscope a fine beam of electrons of medium energy is caused to scan across the sample in a series of parallel tracks. These electrons interact with the sample, producing secondary electron emission (S.E.E), back-scattered electrons (B.S.E.), light or cathodo-luminescence and x-rays.

Samples as large as 25 mm x 25 mm can be accomodated and parts viewed at magnifications from 20 to 100,000 at resolutions of smaller than 200 10^{-10} m in special cases. The depth of the focus is nearly three hundred times that of the optical microscope. The Scanning electron microscope - Stereoscan SEM TL 1153-OM was used to determine the shape of the particles obtained after six hours of sedimentation. Three different layers were obtained after the six hours of sedimentation namely:- the sediment; the clayey solution above the sediment and the suspension above the clayey solution.

This suspension was then centrifuged using Heraeus Christ GmBH Osterode/Harz Picolo centrifuge No. 38836 and filtered by using the Millipore filters (0.22μm porosity). The sediment and the clayey solution were evaporated at 50°C followed by drying in vacuo at 50°C and finally over phosphorus pentoxide (P_2O_5) in a desiccator.

The results indicated that the fines were of irregular shape, some plate or tube-like and of a diversity of colour and sizes.

Photographs were taken and can be seen in AppendixA2. See fig. 3.2 for the sedimentation process after six hours.

3.3.3 THE ELECTRICAL SENSING ZONE METHOD OF PARTICLE SIZE DISTRIBUTION - THE COULTER PRINCIPLE -

The Coulter Counter technique is a method of determining the number and size of particles suspended in an electrolyte by causing these particles to pass through a small orifice on either side of which is immersed an electrode. The charges in resistance as particles pass through the orifice generate voltage pulses whose amplitudes are proportional to the volume of the particles.

The Coulter counter model TA can be used to determine the particle size distribution in the size range of 0.5 to 400/μm of the equivalent spherical diameter. The particle size analysis is available in both volume and weight modes:

(a) frequency distribution percentage,

(b) cumulative distribution percentage,

(c) relative volume frequency distribution,

(d) cumulative relative volume distribution.

The colliery fines were allowed to settle under gravity (gravity sedimentation) for six hours obtaining a sediment, a clayey solution above the sediment and the suspension. The suspension was further fractionated by centrifuging and filtration as carried out in the preparation of the sample for the scanning electron microscopy. These various fractions obtained were then examined using the Coulter Counter Model TA.

In general the particle size distribution was in the range of 3.5 to 92.0μm for the coarsest fraction and 1.24 to 31.5μm for the finest fraction. Detailed results have been tabulated in Appendix A3. These results were graphed in the particle size charts in BS 1377:1975. From these results it was concluded that the fines contained primarily clay, fine, medium and coarse silt and fine sand. See fig. 3.2 for the sedimentation process after six hours.

3.4 THE CHEMICAL ANALYSIS OF THE COLLIERY WASTE-WATER FINES

The elemental analysis was carried out in the first instance by the application of the Energy Dispersive X-ray Microanalysis using the equipment - Link Systems 860.

Energy dispersion is not well suited to quantitative analysis of low concentrations because the shift in the pulse amplitude with counting rate depends on the total counting rate rather than that of the individual element. Thus, there may be an appreciable (but unknown) shift in the amplitude distribution of a low concentration element compared to the standard for that element. This, therefore makes the value of the low concentration element subject to relatively large errors.

The raw colliery waste-water was evaporated at 50°C followed by drying in vacuo at 50°C and finally over phosphorus pentoxide (P_2O_5) in a desiccator. The solid obtained was then ashed, and subjected to chemical analysis according to the British Standards - B.S. 1016 part 14. The procedures given in BS1016 part 14 could not be applied to analyze the oxides of magnesium and iron. The preferred methods in industry for the analysis of the oxides of magnesium and sulphur are the atomic absorption spectrophotometry and Eschka's method respectively.

Microanalytical techniques were applied in the analysis of carbon and other elements which could not be analyzed by the Energy Dispersive X-ray equipment.

The total carbon was found to be 9.2%

Detailed results can be found in Appendix A4.

3.5 MINERALOGICAL ANALYSIS OF FINES IN COLLIERY WASTE-WATER

X-ray powder crystallography was applied to the same samples used for particle size distribution (Coulter-counter) and the lattice spacing calculated from the Bragg equation. These results were compared with the ASTM Index and the minerals tentatively identified are in Appendix A5.

The table X-ray Generator PW-1720 ,and the camera XDC-700 Guinier-Häag were used to carry out the mineral analysis. Aluminium silicates were found to predominate.

The literature survey has indicated that clay minerals are essentially hydrous aluminium silicates, with magnesium or iron substituting wholly or partly for the aluminium in some minerals and with alkaline earth present as essential constituents. Some clays are composed of a single clay mineral but most are mixtures. In addition to the clay minerals some contain varying amounts of the so-called non-clay minerals of which quartz, calcite, feldspar and pyrite are important examples. Also many clay minerals contain organic matter and water soluble salts.

From the Inorganic Index to the Powder Diffraction File (1969) compiled by the Joint Committee on Powder Diffraction Standards, the lattice or d-spacings calculated for the reflections obtained from the X-ray analysis corresponded with those of basic aluminium silicate and aluminium silicate hydroxide. These compounds obtained from the X-ray analysis conform to the elemental analysis (chemical analysis) and also to the particle size distribution chart - BS 1377:1975 fig.10, which gives clays to be present. Clays are basically aluminium silicates.

Results of the mineralogical analysis can be found in Appendix A5. See fig. 3.2 for the preparation of the samples for X-ray crystallography.

3.6 THERMAL ANALYSIS OF THE CLAY MINERALS

The methods of thermal analysis have provided an invaluable aid for the determination of the composition of some native or artificial compounds and minerals. They are based on the chemical processes and physical phenomena which occur in a solid when it is heated(112).

The samples were prepared in the same way as that for the scanning electron microscopy and the size distribution by the Coulter counter equipment.

These samples were analysed using the differential scanning calorimeter - Model DSC-2 and thermogravimetric system Model TGS-2.

Two thermal peaks were obtained in each case the first occuring around 100°C and the second around 450°C to 550°C.

The first peak corresponds to the loss of water and the second is probably due to the decomposition of organic matter. The presence of the organic portion present prevented any detailed interpretation of inorganic constituents present in the colliery fines. Hence unless the organic fraction can be physically separated from the rest, identification would not be possible. Consequently attempts were made to separate the coal-inorganic constituents by heavy liquid density gradient fractionation.

3.7 HEAVY LIQUID DENSITY GRADIENT FRACTIONATION

The heavy liquid density gradient technique enables the separation of a physical mixture of clay minerals provided their densities do not overlap one another. The technique is based on a column of heavy liquid (Clerici solution) (113,114,115,116) in which the density decreases continuously from the top to the bottom of the column. The individual particles settle at their appropriate density levels to form sharply defined mineral layers upon adding a mixture of liberated minerals to such a column. Interstitial clay minerals, and minerals with a continuous, overlapping density range do not yield separate zones. They can only be fractionated by taking samples from different portions in the zones. A banked or staircase-shaped gradient may create artificial zoning and facilitate isolation of samples.

There was no separation of the clay minerals-coal particles in distinct zones and bands. All the samples introduced into the mixture of thallium malonate and thallium formate (Clerici Solution) which have been put in the density gradient column remained together in the same zone. Thus this method could not be applied to the separation of the colliery fines.

3.8 FRACTIONATION BY GRAVITY SETTLING (PIPETTE METHOD)

Owing to the failure with the heavy liquid density gradient fractionation, gravity settling (sedimentation) was examined to see if any fractionation occured.

Twenty samples were taken using the pipette method- BS 1377:1975.

If separation had taken place on the basis of particle size and weight then these samples should be different from one another.

These twenty samples were subjected to particle size distribution using the Coulter Counter Model TA and chemical analysis using the Energy Dispersive X-ray equipment, X-ray crystallography and thermal analysis.

The results were the same as the original sample indicating that negligible separation had occured and that the solid fines are very intimately mixed and therefore very difficult to fractionate.

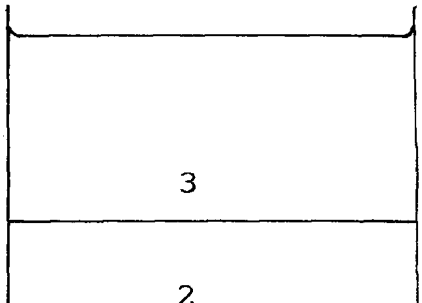


Fig. 3.2 Sedimentation after (6) six hours.

1 - Sediment after six hours of settling (A1 & A2)

2 - Clayey solution obtained after six hours of settling (B1 & B2)

3 - Suspension obtained after six hours of settling:-

C1 and C2:-	Solid fines obtained after filtration using Millipore membrane filters of 0.22μm porosity
D1 and D2	Solid fines obtained after centrifuging.

DESCRIPTION OF MICROELECTROPHORETIC APPARATUS

CHAPTER 4

4.1 INTRODUCTION

Various experimental techniques have been developed for studying the electrokinetic effects by many authors including Tiller(2), Hunter(4), Mackenzie(10), Overbeek(12) and Ross(50). These experimental techniques include; electrophoresis (micro-electrophoresis), electro-osmosis, streaming and sedimentation potential. Having considered these techniques the method of microelectrophoresis **was** applied to the study of the electrokinetic effects on the colliery waste-water.

Shaw(49) has reviewed the experimental techniques of electrophoresis and its practical applications. Hunter(4) has also reviewed the measurement of electrokinetic parameters.

Electrophoresis is the most common procedure for the determination of zeta potential and several techniques have been developed for the application to different types of material(2,4,40,50). Micro-electrophoretic procedure is the movement of individual particles in the colloidal size range under the influence of an electrical field. This movement of the particles is followed directly in an ultramicroscope assembly or dark-field microscope.

Only very dilute sols can be studied by the technique of micro-electrophoresis. The particle concentration must be so low as to induce only the slightest haziness in the solution, since interparticle interference and multiple light scattering may make the results invalid. Dissolved materials can also be studied in this way if they are adsorbed on to carrier particles.

4.2 MICRO-ELECTROPHORESIS

Much of the pioneering work on micro-electrophoresis (electrophoresis) was done without stabilizing media. Picton et al(120) appear to have originated the method in 1892, but it was not developed until 1937 when Tiselius(130) described the apparatus and methodology.

Until quite recently almost all the work on electrophoresis was applied in the separation of proteins and blood cells. Thus electrophoresis was mainly used in biochemistry and clinical work.

Bull(118) carried out experimental work in which he made a critical comparison of electrophoresis, electro-osmosis and streaming potential in which he modified the electrophoretic cell.

The zeta potential is rather difficult to measure experimentally and many authors(1,2,4,7,10,40,128,129) have measured the electrophoretic mobility of the particles and hence the calculation of the value of the zeta-potential.

Electrophoretic mobility measurements were performed on kaolinite by Street and Buchanan(124). Bangham et al(125) have designed and constructed an apparatus for micro-electrophoresis of small particles. An improved version was designed by Smith(126) and marketed by Rank Brothers (Bottisham, Cambridge, England). Black et al(127) investigated the electrophoretic mobility of colloidal particles by applying the method of micro-electrophoresis.

Deju et al(128) have constructed a modified electrophoresis apparatus for the determination of zero point of charge for quartz. The electrophoretic mobilities of quartz, beryl and microline were also investigated to determine the zero point of charge.

The electrophoretic velocity of colloidal particles can be determined by the direct observation of a colloidal sol in a closed capillary tube.

4.2.1 MICRO-ELECTROPHORETIC CELL DESIGN

Many workers including Mattson(117), Bull(118), Smith et al(119) and Rutgers et al(123) have reviewed the various cells which have been used in the study of micro-electrophoresis. The cells are easily cleaned, rugged and reliable.

The prominent features of the various micro-electrophoretic cells have been described by Shaw(40) presenting line drawings of the designs by Mattson(117) and Alexander et al(122).

A micro-electrophoresis cell consists simply of an observation tube of either circular or rectangular cross-section with an electrode at each end and with inlet and outlet taps attached. Shaw(40) observed that the micro-electrophoretic measurements are complicated by the simultaneous occurence of electro-osmosis near the walls of the cell. The initial surface of the cell are generally charged, and the applied electrical field causes an electrophoretic migration as well as electro-osmosis flow of liquid near to the tube walls together with a compensating return flow of a liquid with maximum velocity at the centre of the tube since the cell is usually closed. This results in a parabolic distribution of liquid speeds with depth and the true electrophoretic velocity is observed only at the stationary levels in the cell where the electro-osmosis flow and return flow of liquid cancel.

Mattson(117) has constructed a cylindrical cell for use in the study of electrophoresis. The cell was in a series of investigations dealing with the iso-electric precipitation of a number of complex precipitates such as silicates, phosphates and proteinates of aluminium and iron.

Smith and Lisse(119) constructed an electrophoretic cell for the microscopic observations of the velocities of particles. An apparatus was designed for quantitative electrophoretic work using different cells by Alexander et al(122) in the determination of electrophoretic mobility. Rutgers et al(123) also constructed an electrophoretic cell.

Electrophoretic mobility measurements were carried out by Street and Buchanan(124) by constructing the electrophoretic cell from a pyrex capillary with flat grounds.

More recently Shergold et al(129) have designed a demountable electrophoretic cell for work on mineral particles. The electrophoretic mobility of a suspension of Fransil - a finely divided vitreous silica powder in distilled water was determined. The cell design was based on a commercially available spectrophotometer cell with **open** ends.

4.2.2 OPTICAL SYSTEM OF MICRO-ELECTROPHORESIS

Shaw(40), Hunter(4), Smith et al(126) and Shergold et al(129) and many research workers have used dark-field illumination in which the electrophoretic cell is illuminated at right angles to the direction of observation.

The optical system of the microscope should consist of a long working distance objective to permit focusing on any level within the electrophoretic cell(4,40,129). The degree of magnification should be high in order to minimize the depth of focus and permit accurate location of the particles at stationary levels.

The eyepiece is equipped with a graticule to enable the distance travelled by each particle to be measured in a given time(4,40,125,126).

4.2.3 ELECTRICAL SYSTEM OF MICRO-ELECTROPHORESIS

A power supply which is stabilized against the mains fluctuation should be applied to produce the electrical field in the electrophoretic cell(4,40,119,125,127,129). The voltage rather than the current should be maintained constant, if the effective length method for determining the field strength is applied.

Electrodes are selected with the view of either eliminating or reducing polarization at the electrode(4,40,128,129) and the contamination of the observation chamber with electrode material.

4.3 A MODIFIED MICRO-ELECTROPHORETIC APPARATUS FOR ELECTROKINETIC MEASUREMENTS OF THE COLLIERY WASTE-WATER

The phenomenon of micro-electrophoresis has been studied for many years and a lot of work has been carried out in designing an apparatus to improve upon the measurements of mobility, zeta-potential and the point of zero charge of minerals. Until presently most electrophoretic experiments have involved cumbersome equipment, tedious microscopic observation and the use of dark-field illumination.

The modified micro-electrophoretic apparatus which has now been designed for the measurements of electrophoretic mobility, particle charge, and zero point of charge and iso-electric point of charge combines the simplicity of construction with an improved method of measurement of velocity of the particles and the reduction of the contamination of the cell. The images of the particles were projected onto a television screen and this eliminates the need for tedious measurement of the velocity of the particles using the microscope graticule. It utilizes the ultra-microscope principle of direct illumination and the light source is placed directly below the electrophoretic cell.

The general set-up can be seen in Figs. 4.1 and Fig. 4.2.

4.3.1 DESIGN AND CONSTRUCTION OF THE MICRO-ELECTROPHORETIC CELL

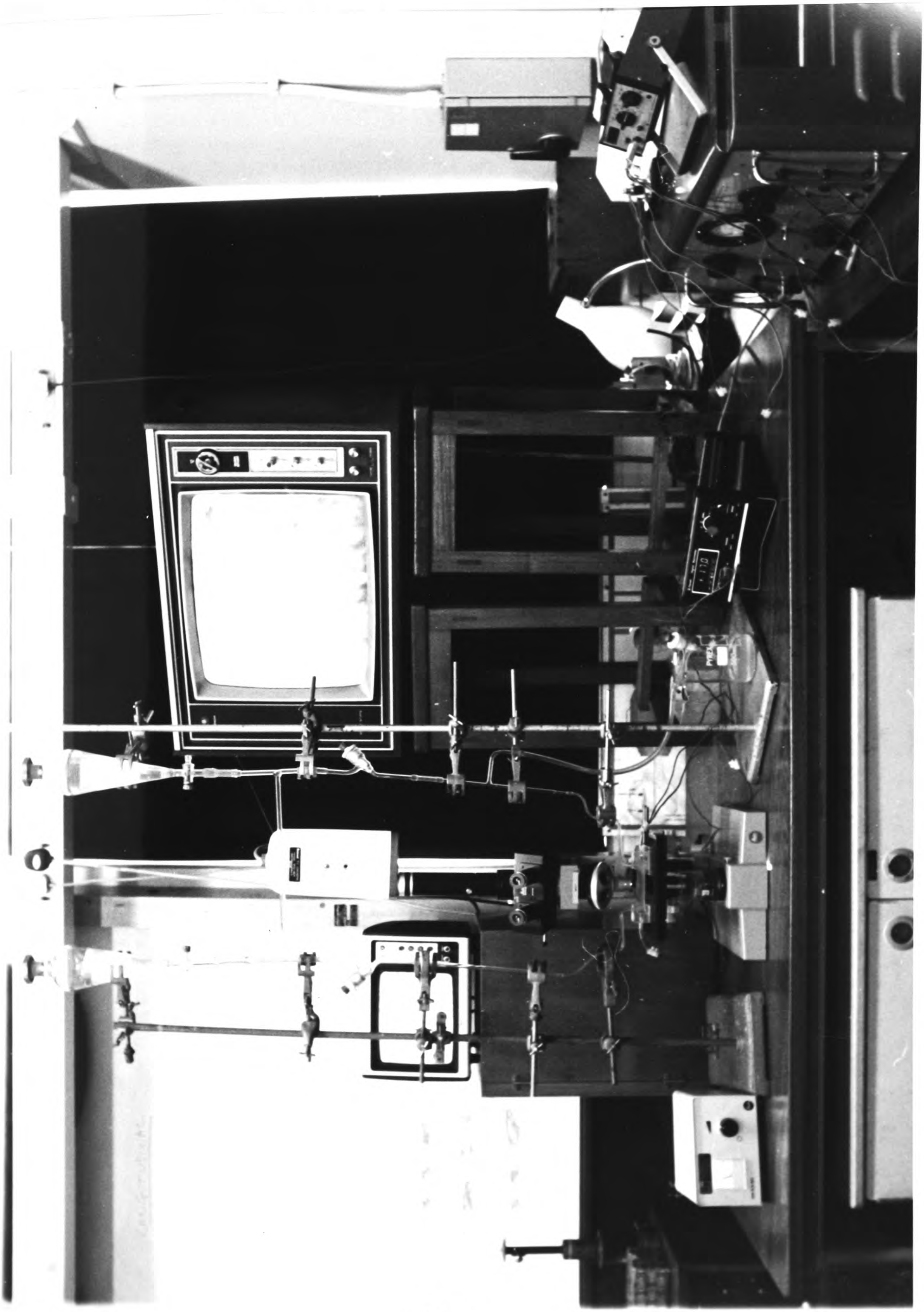
The electrophoretic cell consists of two similar electrode compartments and a perspex cell. The electrode compartments were machined out of solid rectangular blocks of perspex. The perspex cell was supplied by Hughes and Hughes (Romford, Essex), and it is 1-mm standard spectrophotometer cell, 40-mm long and 10-mm wide with an open and closed end. The perspex cell is then fitted into the two electrode compartments by slots which have been machined onto one face of each electrode compartment. The rectangular cell is preferred to the cylindrical cell since it has gained more adherents recently owing to the optical difficulties associated with the cylindrical design.

The platinised wire which is used as an electrode is then passed through a perspex tube (see Fig. 4.2) into the electrode compartment and is held in position by perspex glue.

The sample is then passed in and out of the electrophoretic cell through holes in which have been drilled on top of the electrode compartments into the cell. During filling of the cell with the sample, air is allowed to escape through the other hole drilled in the electrode compartment by opening the exit valve.

When the cell is in use the electrophoretic cell and the capillary tubes joining the cell and the reservoirs are completely filled with the sample.

Fig. 4.1 Photograph of the Assembly of the modified micro-electrophoretic apparatus.



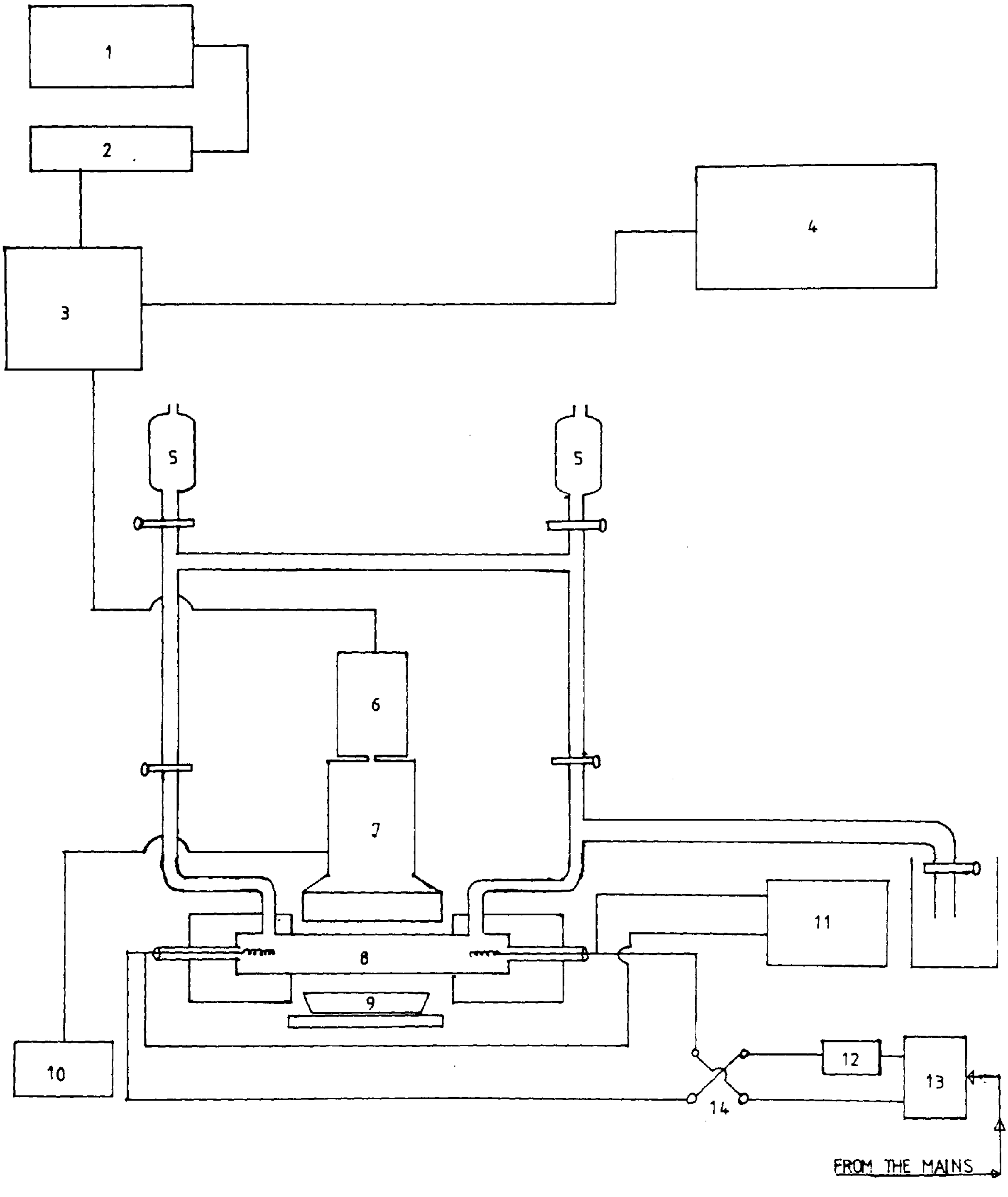


FIGURE.4.2. ASSEMBLY OF THE MODIFIED MICRO-ELECTROPHORESIS APPARATUS

1. TELEVISION SET FOR RECORDING
2. VIDEO-CASSETTE RECORDER
3. TELEVISION MONITOR
4. TELEVISION FOR MEASURING VELOCITY OF PARTICLES
5. RESERVOIR TANKS FOR SAMPLE
6. TELEVISION CAMERA
7. MICROSCOPE AND LAMP HOUSING
8. ELECTROPHORETIC CELL
9. COPPER SULPHATE SOLUTION-HEAT FILTER
10. LIGHT SOURCE
11. VOLTMETER
12. AMMETER
13. POWER UNIT-CONVERTER
14. REVERSING KEY

This assembly is easily clamped to the microscope stage and demounted to allow cleaning to be carried out without constraint.

Detailed design of the electrophoretic cell can be seen in Fig. 4.3.

4.3.2 OPTICAL SYSTEM

The optical arrangement of the modified micro-electrophoretic apparatus comprises these equipments:-

a) Metallux-2 Metallographic microscope-Ernst Leitz GmBH D-6330 WETZLAR.

b) Levis-Leitz Wetzlar, Achromats NPL 10X/0.20, with free working distance of 14.2mm and focal length of 25.0mm.

c) Television Camera-National Miniature CCTV System, TV Camera WV-401.

d) Television Monitor - National WV-411.

e) Television Screen - Hitachi Solid State TU-201K

f) Video Recording Set-up

   (i) Video recorder-SONY Serial No. 15616
   U-matic video cassette recorder - (VO-1810 U.K.)

   (ii) Television Set-Sony Trinitron Colour T.V.
   Receiver Serial No. 525761

g) Light Source - Leitz Wild Heerbrugg and Ernst Leitz Wetzlar GmBH. Wild Best Nr.319553, Leitz Best Nr.500253.

h) Heat filter - Copper Sulphate Solution - 25% by weight (25gm in 100cc)

FIGURE. 4.3 DESIGN OF THE MICRO-ELECTROPHORETIC CELL

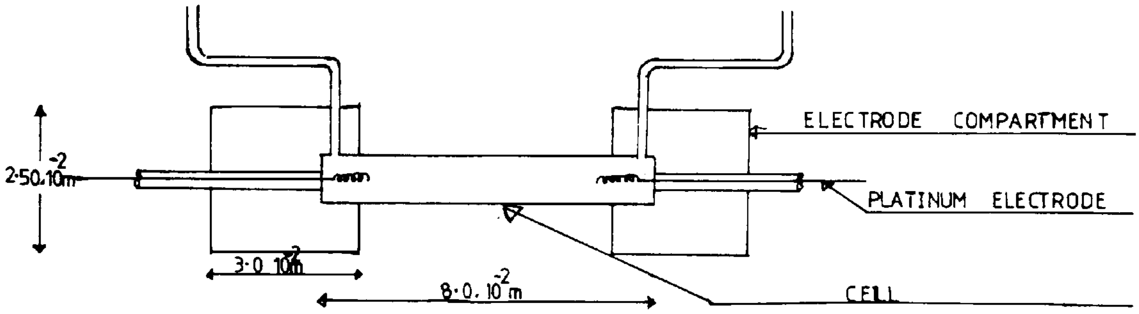


FIGURE 4.3a. FRONT-VIEW OF THE MICRO-ELECTROPHORETIC CELL

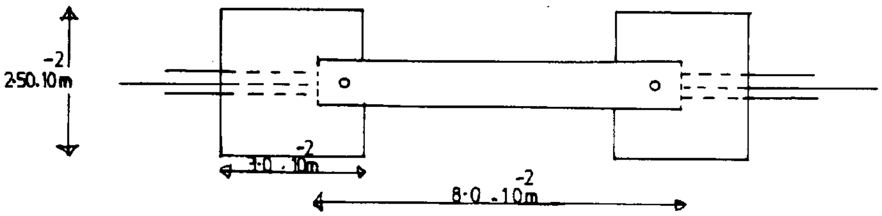


FIGURE. 4. 3b TOP-VIEW OF THE MICRO-ELECTROPHORETIC CELL

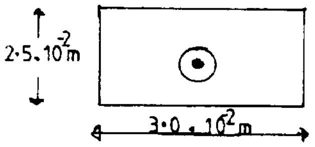


FIGURE. 4.3c SIDE-VIEW OF THE MICRO-ELECTROPHORETIC CELL

4.3.3 ELECTRICAL SYSTEM

The electrical arrangement of the micro-electrophoresis apparatus comprises the following:-

a) Regulated Power Unit Model SRS 152 Serial No. 24357 - Solartron Laboratory Instruments Ltd., Thames Ditton, England.

b) Digital Multimeter Alpha 11 - Serial No. 3350.

c) Farnell Digital Multimeter - Model DM131/B Serial No. 001465.

The regulated power unit converts the alternating current (AC) from the mains to direct current (DC) which can be used to perform electrophoresis.

The Digital Multimeter - Alpha 11 is used to measure the current which passes through the electrophoretic cell and this can measure current in the range 1μA to 1000mA.

The Farnell digital multimeter is also used to measure the voltage across the electrophoretic cell to enable the determination of the potential gradient.

4.4 ELECTROPHORETIC MOBILITY OF QUARTZ

The electrophoretic mobility of quartz, the zero point of charge and the iso-electric point were determined using the modified micro-electrophoretic apparatus which has been described in paragraph 4.3 and fig. 4.2. This was carried out to establish the validity of the modified micro-electrophoretic apparatus which has been designed and constructed for the study of the electrokinetic parameters of the colliery waste-water. The results obtained agreed within experimental error with the work published by Bhappa et al(128).

There was a slight modification in the size of the modified electrophoretic cell chamber which had to be reduced to $4.0\ 10^{-2}$ m owing to the low conductivity of the quartz suspension as compared to the colliery waste-water. The optical system remained exactly the same as **did the** electrical system.

4.5 VARIATION OF pH WITH CONDUCTIVITY

The pH of the colliery waste-water was determined by the addition of various quantities of acids and then measuring the corresponding conductivity. This was also carried out on the quartz suspension.

The apparatus set up to study the variation of pH with conductivity comprises these equipments:-

a) pH-meter Model 7020

b) Conductivity Meter - Type CDM 2e No. 263049

c) Magnetic Stirrer MS1-Techre

The pH meter model 7020 is a direct indicating instrument for the measurement of pH, with automatic or manual temperature compensation, and millivolts.

It is designed for use with the following classes of electrodes manufactured by Electronic Instruments Limited (E.I.L).

a) pH dual (Model SHDN33C)

b) pH measuring and reference pairs

c) Redox measuring and reference pairs.

The principle of the conductivity meter is that of an ohm-meter. The conductivity of the conductivity cell is read directly from the indicating meter, and the specific conductivity of the test liquid at the specified temperature.

The conductivity cell type CD104 has three electrodes in the form of platinum sheet placed in rings around a glass tube and enclosed in a glass jacket. The top and the bottom rings are connected and grounded to chassis through the shield of co-axial cable while the centre ring is connected to the centre conductor of the cable. This arrangement which is a special feature of the conductivity cell has an effective electrical shielding of the flows of currents between the electrodes, thus enabling the cell to be used for measurements in grounded vessels.

EXPERIMENTAL STUDY

CHAPTER 5

5.1 INTRODUCTION

The study involves the measurement of the electrokinetic parameters such as; electrophoretic mobility, the zero point of charge, the nature of charge and the iso-electric point. The values of the electrophoretic mobility obtained can then be used in the calculation of the zeta-potential.

The particle concentration should be so low as to induce only the slightest haziness in the solution, otherwise interparticle interference and multiple light scattering may make the results invalid. Thus in order to demonstrate electrophoresis the solid has to be in the form of particles which are sufficiently small to remain suspended in the liquid during the application of the electrical field and the measurement of their velocity. The particles must also be small enough or have a density close enough to that of the suspending medium so that they will **not** fall out of the stationary level under the influence of gravity while they are observed.

Any charged particle suspended between the poles of an electrical field tends to travel towards the pole that bears the charge opposite to its own. When particles of several kinds are present and each kind having its own characteristic mobility, a number of particles may be measured so that the distribution of mobility may be obtained. The rate at which the particles travel is conditioned by a number of factors including the characteristics of the particle, the properties of the electrical field and environmental factors such as temperature and the nature of the suspending medium. The microscopic determination of electrophoretic mobility has been applied successfully to such diverse aqueous systems such as kaolinite(124,131), and quartz(128).

The electrophoretic mobility of a particle is approximately proportional to its charge to mass ratio but unfortunately this relationship is complicated by such factors as the molecular volume of migrant, co-ordination of the migrant with the molecules of solvent and the interference with migration by the supporting medium(132).

Factors such as these make it very difficult to make accurate quantitative predictions of electrophoretic mobilities unless experimental data are available. When a solution containing substances with different charge to mass ratios is acted upon by an electrical field, the components tend to migrate at different rates.

5.2 REAGENT AND PREPARATION OF SAMPLES

Analar (BDH, Chemical Ltd.) reagents were used.

Concentrations of 0.4M, 0.5M, 0.8M, and 1M HCl were prepared for use in studying the variation of pH with conductivity of the suspension of the colliery waste-water and 100ppm of Quartz suspension.

Various amounts of 0.4M. HCl were added to 1000ml of the suspension of the colliery waste-water to obtain different pH values from which the electrokinetic parameters could be determined experimentally.

Different amounts of 0.4M HCl were added to various volumes of the suspension of the colliery waste-water to obtain different pH values to carry out the experimental work on flocculation.

Concentrations of 0.4M, 0.5M, 0.8M, and 1M. H_2SO_4 were prepared for use in studying the variation of pH with conductivity of the suspension of the colliery waste-water and 100ppm of Quartz suspension.

Various amounts of 0.4M H_2SO_4 were added to 1000ml of suspension of the colliery waste-water to obtain different pH values for the study of the electrokinetic parameters.

A concentration of 100ppm of Quartz suspension was prepared using silica precipitated acid washed - (SiO_2, BDH Chemical Ltd., Product No. 30058). Different amounts of 0.4M HCl were added to 1000ml to obtain the various pH values to be used to study the electrokinetic parameters.

Twenty - five percent weight per volume (25% $\frac{W}{V}$) of the copper sulphate solution ($CuSO_4 . 5H_2O$ - BDH Chemicals Ltd.) was prepared to be used as heat filters.

A concentration of 100ppm of Polyacrylamide solution (BDH Chemicals Ltd., Product No. 29788, Molecular weight over 5,000,000) was prepared to be used as the flocculating agent for the suspension of the colliery waste-water.

Chloroplatinic acid (BDH Chemical Ltd., 5% $\frac{W}{V}$ $H_2PtCl_6 6H_2O$) was used as the platinising solution in the preparation of the platinum black electrodes for the study of electrophoresis(133)

The raw colliery waste-water was allowed to stand for twenty-four hours and the suspension was decanted. This suspension was used in the study of electrophoresis. Various amounts of 0.4M HCl and 0.4M H_2SO_4 were added to 1000ml of the colliery waste-water to obtain the different values of pH values for electrophoresis.

5.3 SAFETY PRECAUTIONS

The electrophoretic cell should be made of an insulating material and designed so that any liquid spilling from the apparatus cannot create an electrical hazard. The cell should also be designed in such a way that the power supply should be disconnected before the discharge of the suspension from the cell.

To avoid the danger of making voltage measurements with platinum wires (electrodes) being bare in the external circuit, these terminals should be of the jack-type and the wire should be passed through a perspex tube, making it impossible to touch the live wires and cell should be closed.

Handling the raw colliery waste-water should be carried out with the utmost care since Eschericia Coli (E.Coli) was detected and it is an organism used as an indicator of faecal contamination and possible presence of pathogenic organisms.

5.4 EXPERIMENTAL PROCEDURE

Electrophoresis was performed on the silica (quartz) suspension to confirm the validity of the modified micro-electrophoresis equipment and then on the suspension obtained from the raw colliery waste-water.

The variation of pH with conductivity and the various amounts of the acids (HCl and H_2SO_4) required to obtain the pH values for electrophoresis were determined.

Finally the flocculation of the fines in the suspension was carried out using the polyacrylamide.

5.4.1 ELECTROPHORESIS OF THE FINES IN THE SUSPENSION OBTAINED FROM THE COLLIERY WASTE-WATER.

The experimental set-up used for the micro-electrophoresis is shown in Figure 5.1.

The external electrical circuit was connected as shown in Figure 5.1. The Regulated Power Unit (V.1) used in converting the alternating (a.c.) to the direct current (d.c.) was connected to the ammeter (A) and then the reversing key which was in turn, connected to the electrodes in the micro-electrophoretic cell. A voltmeter (V2) was connected across the micro-electrophoretic cell to measure the voltage across the cell.

The micro-electrophoretic cell was then placed on the microscope stage and then connected to the tubes and the funnels being used as the reservoirs (R1 and R2), as illustrated in Figure 5.1.

All the taps (T1,T2,T3,T4 and T5) are then closed. The reservoir, R1, was then filled with the suspension and reservoir, R2, was then filled by opening taps T1 and T2. Having filled the two reservoirs, the tap T2, was then closed and Taps T3 and T5 were opened so that the micro-electrophoretic cell could be filled. After filling the micro-electrophoretic cell, there were a few bubbles in the cell which had to be removed by closing tap T5 and opening Taps T2 and T4. This allowed any bubble in the micro-electrophoretic cell and the connecting tubes to move up into the reservoirs. When all the bubbles had been removed the taps T1, T2, T3, and T4 were then closed.

The light source (L.S.), the monitor (M) and the television screen (TV 1) were switched on. A calibrated screen was already placed on the television (TV1), and was used in measuring the distances travelled by the fine particles in the cell.

Copper sulphate (25% $\frac{w}{v}$) was installed between the microscope lamp and the micro-electrophoretic cell and this was used as a heat filter.

The Regulated Power Unit (V1) was then switched on to confirm if the other equipments were working correctly and to see if the fine particles were moving in the cell and then the power source (V.1) was switched off to allow the suspension in the cell to attain equilibrium which usually took between seventy - five and ninety minutes.

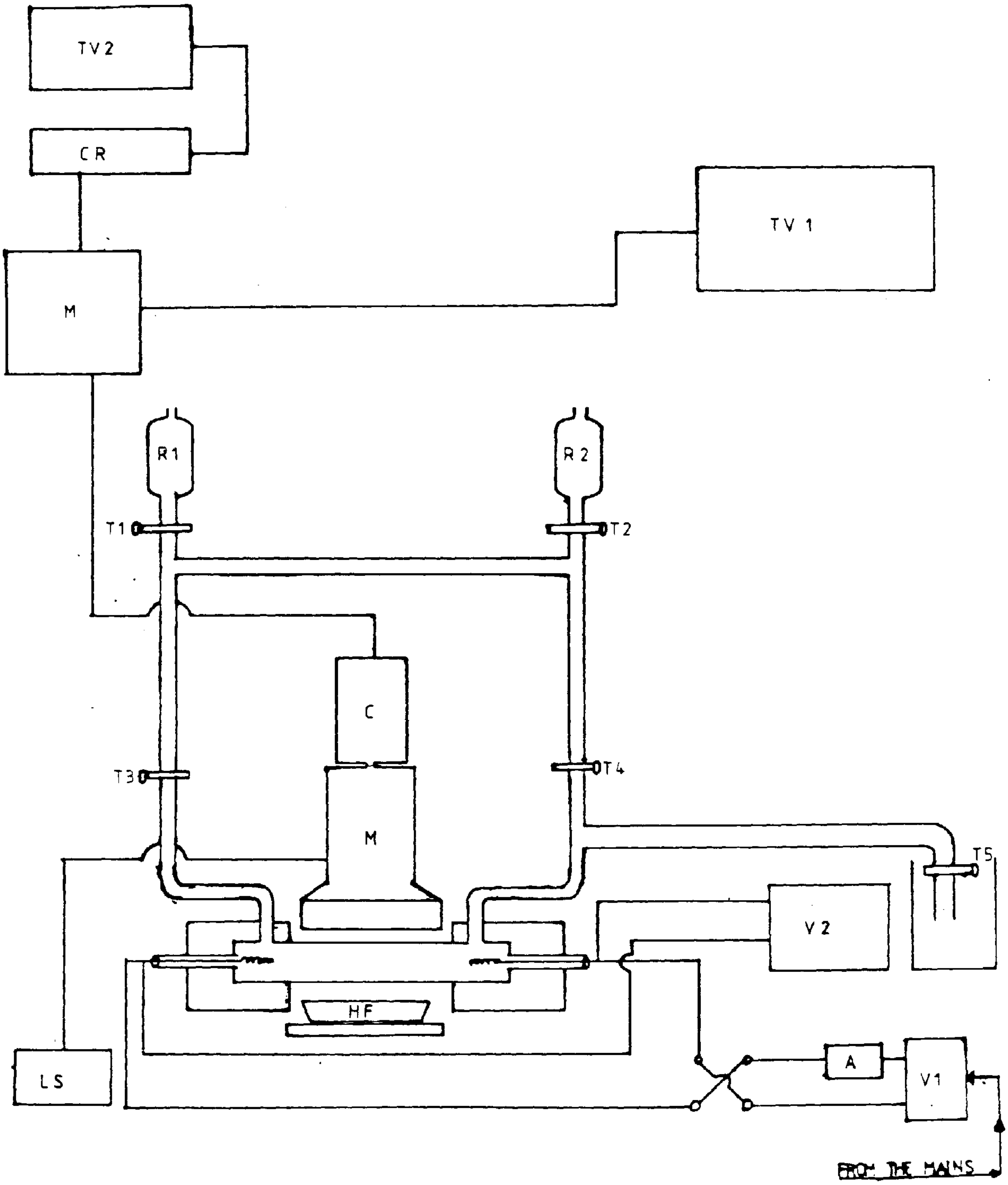


FIGURE 5 1 EXPERIMENTAL SET-UP FOR MICRO-ELECTROPHORESIS

Having obtained the equilibrium condition, the power source and the light source were switched on, with the micro-electrophoretic cell being held tightly on the microscope stage. The microscope was then focused at the appropriate level in the cell by the calibrated fine and coarse adjustment of the microscope.

The time taken for several particles to travel given distances on the television screen (T.V.1) were measured using the stop clock watch (measuring to 0.1 second). The times taken for several particles to travel different depths in the cell were then measured.

This procedure of timing the particles were then repeated for suspensions of different pH values to determine the zero point of charge and to calculate the electrophoretic mobility at different levels in the cell and hence the zeta-potential.

Having measured the velocity at each level in one direction the polarity of the direct current was reversed since the reversal cancels out assymetric effects and reduced the polarisation effects.

5.4.2 ELECTROPHORESIS OF QUARTZ SUSPENSION

Electrophoresis of the Quartz suspension was carried out to confirm the validity of the equipment designed. The results obtained would then be compared with the work done by Bhappu et al(128).

The same experimental procedure described for the suspension of the colliery waste-water in 5.4.1 was applied to the quartz suspension. The only difference was in the length of the micro-electrophoretic cell which in this case had to be reduced from $8.0.10^{-2}$(m) to $4.0.10^{-2}$(m) for the quartz suspension, since the conductivity of quartz suspension was so low compared to the suspension of the colliery waste-water.

5.4.3 FLOCCULATION OF THE SOLID FINES IN THE SUSPENSION (COLLIERY WASTE-WATER)

Different amounts of 1M HCl were added to eight beakers containing 200ml of the suspension (colliery waste-water) to obtain the various values of pH 2.1, 3.0, 4.0, 4.9, 6.0, 7.0, 7.8 and 8.7 (original pH of the suspension).

An amount of 20ml of 100ppm of polyacrylamide was added to each beaker containing the suspension and allowed to stand for twenty four hours. Changes in flocculation were assessed by measuring their optical densities.

5.4.4 THE CLEANING OF THE APPARATUS

The apparatus is demounted into three separate parts:- the two reservoirs, the tube (piping) connecting the cell and the reservoirs; and the electrophoretic cell.

The reservoirs are washed in a solution of teepol. The tubes and the electrophoretic cell are also washed in the solution of teepol and then cleaned by the ultrasonic disintegrator (SONIPROBE TYPE 7530 A SERIAL No. 3892).

The reservoirs, the tubes and the electrophoretic cell are then rinsed with de-ionised water and dried in an oven at 100°C.

5.5 ANALYTICAL PROCEDURE

Electrophoretic mobility is defined as the ratio of the velocity of the particles to the potential gradient.

The velocity is measured by timing a number of particles travelling over a distance.

$$u = \frac{x}{t} \qquad (5.1)$$

where; u is the velocity $(m.sec^{-1})$

x is the distance travelled by the particles in the electrophoretic cell, (m).

t is the time taken to travel the distance, (sec).

The distance x, is obtained by measuring the distance X, travelled on the television and then dividing by the magnification ratio between the monitor screen and the magnitude of the objective lens, M.

$$x = \frac{X}{M} \quad (m) \qquad (5.2)$$

where; X is the distance travelled by the particles on the television screen, (m).

M is the magnification ratio between the monitor and the magnitude of the objective lens.

The potential gradient is defined as the ratio of the voltage to the effective length between the electrodes. Three methods of measuring the voltage gradient are known(4);

$$E = \frac{V}{l} \qquad (\text{volt. m}^{-1}) \qquad (5.3)$$

where; E is the potential gradient, (volt. m^{-1})

V is the voltage across the cell, (volt.)

l is the effective length between the electrodes, (m).

The voltage, V, is measured by connecting a digital voltmeter across the cell. The effective length is calculated by the application of the following formula;

$$l = R\lambda A \qquad (\text{m}) \qquad (5.4)$$

where; R is the resistance across the cell (ohm).

λ is the electrical conductivity, (ohm^{-1}. m^{-1})

A is the cross-sectional area, (m^2).

Hence the electrophoretic mobility, μ, is calculated as;

$$\mu = \frac{u}{E} \qquad (\text{m}^2.\text{sec}^{-1}.\text{volt}^{-1})$$

The zeta-potential, ξ ; is then calculated by the application of this formula;

$$\xi = \frac{4\pi\eta \, . \, \mu}{D} \qquad (\text{volt}) \qquad (5.6)$$

where; η is the viscosity of the medium (kg m^{-1} s^{-1})

D is the dielectric constant of the suspending medium.

ξ is the zeta potential, (volt)

The point at which the zeta potential is zero is called the iso-electric point (i.e.p.). In electrophoresis this is the situation where the electrophoretic mobility becomes zero.

The zero point of charge (z.p.c.) of a mineral can be defined as the point on the pH scale at which the mineral possesses no surface charge and the adsorption densities of H_3O^+ and OH^- are equal. At the zero point of charge both the surface potential and zeta potential are zero.

Changes in suspensions due to flocculation can be assessed turbidimetrically or even visually but the results are difficult to interpret quantitatively. Changes in turbidity normally assess the progress of flocculation, either by nephelometry (light scattering) or absorptiometry (light transmission, measured by optical density).

The measurement of intensity of the transmitted light as a function of the concentration of the dispersed phase is the basis of turbidimetric analysis. Hence the method of turbidimetry can be applied in the determination of the suspended material in the colliery waste-water. The intensity of the light scattered at any particular angle is a function of the concentration of the scattering particles of their size and shape, of the wavelength, of light, and of the difference in refractive indices of the particles and the medium.

Thus using the Perkin-Elmer (Lambda 3uv/vis) Spectrophotometer and Recorder Model 561 (Hitachi Ltd., Tokyo, Japan), the optical densities of the colliery waste-water suspension at the various pH values can be determined directly after flocculation with 100ppm of polyacrylamide flocculant. Any settling of the colliery fines would tend to decrease the optical density as measured through the medium.

INTERPRETATION OF DATA

CHAPTER 6

6.1 INTRODUCTION

Electrokinetic phenomena are only directly related to the nature of the mobile part of the electrical double layer and therefore can only be interpreted in the terms of zeta potential or the charge density at the surface of shear. Since the value of the zeta potential cannot be determined experimentally, it is usually calculated from the electrokinetic data, by measuring the electrophoretic mobility. These values of dielectric constant and viscosity of the bulk solution could be different from those values in the electrical double layer making the calculated value of the zeta potential uncertain (4,10,40,48,56,61,62).

It is frequently adequate to measure only the relative changes in the electrokinetic properties such as the mobility and the point of zero charge in the application of the electrokinetic data in understanding the behaviour of the mineral-water systems(10). The calculation of absolute values of zeta potential is not necessary in such analysis of data, particularly if the experiments have been carried out at constant ionic strength. However, it may be necessary to use an absolute value of the zeta potential for more detailed analyses of the influence of the electrical double layer properties on the behaviour of mineral systems(4,10).

The zeta potential or electrokinetic charge which surrounds practically all particulate matter in water is predominantly electronegative and it is usually strong enough to result in significant mutual repulsion(69,141,142).

Therefore finely divided solids such as clay tend to remain suspended. If the charge on these particles is reduced to zero or near zero the repulsive forces are reduced or eliminated which result in agglomeration and subsequently in sedimentation. The efficiency of the process of the clarification of the colliery waste-water (effluent water) is markedly influenced by agglomeration. Therefore zeta potential analyses may help to evaluate the flocculating characteristics and aid in determining the type of flocculants most useful and effective in the clarification of the colliery waste-water.

6.2 THE CONCEPTS OF ELECTROPHORETIC MOBILITY

The theory of electrokinetic phenomena, one of which is electrophoresis was first presented by Helmholtz(134), in which he concluded that the electrophoretic mobility is proportional to the zeta potential and not the charge of the colloidal particle. The derivation of Helmholtz was then improved by Smoluchouski(135), to be completely consistent with this more modern view of the double layer(59). Smoluchowski's equation is identical with that developed by Helmholtz except for the inclusion of the dielectric constant.

Overbeek(56) has found out the stability of hydrophobic colloids to be closely related to the zeta potential as calculated from electrophoretic mobility by the application of electrophoresis. To keep the hydrophobic suspension stable, it was determined to be necessary that a specified minimal zeta potential (critical potential) was found. This concept has been widely used by many authors(4,10,37,40,50,73,96,124), and although the zeta potential has a less prominant position (56), electrophoresis still remains an important source of information about hydrophobic colloids. The relation between stability and electrophoresis is much less prominent in hydrophilic colloids since many hydrophilic colloids may remain in colloidal solution even when their electrophoretic mobility has been reduced to zero. Nevertheless electrophoresis would retain its significance in the determination of the iso-electric point and the charge of the particles outside the iso-electric point.

A number of workers including Henry(59), Lyklema and Overbeek(61) and Hunter(62) have investigated the various corrections required to preserve the validity of Smoluchowski's equation. Retardation, relaxation and viscoelectric effects have been considered the most significant aspects requiring correction.

The retardation effect has been analysed by Henry(59) and shown to be a function of the ratio of the radius of the particle to the thickness of the electrical double layer (ka). The relaxation correction is more complex because it depends strongly on the ratio of the particle radius to the electrical double layer thickness and it is also influenced by such factors as the magnitude of the zeta potential, the valency and the mobility of the ions in the solution.

The possibility that the viscosity and permittivity constant terms in the Smoluchouski's equation could be influenced by the locally high-field strength gradients of the electrical double layer has been considered by Lyklema and Overbeek(61) and Hunter(62).

Wiersema et al(137) have carried out the calculation of the electrophoretic mobility of a spherical colloidal particle.

In a comprehensive review Overbeek et al(12) considered the effect on zeta potential calculation of mixtures of electrolytes, errors in the Gouy-Chapman theory, the visco-electric effect, particle conductivity, non-rigid particles, particle chape, Brownian movement and colloid concentration.

More recently Morrison(143) has considered in detail the effect of the particle shape and has concluded that equations developed for spheres are applicable to other shapes.

Despite the attention given by many workers to the calculation of the zeta potential from the electrophoretic mobility data and despite the improvements which have been made, it is obvious that there are still areas of uncertainty.

6.2.1 SMOLUCHOWSKI'S EQUATION

Smoluchowski's analysis was carried out in the first instance by studying electro-osmosis and his electrophoresis equation was derived by considering electrophoresis as the reverse phenomenon of electro-osmosis and therefore for the relative motion of the solid and liquid, the same equation should apply to both phenomena.

In direct application to electrophoresis, Smoluchowski deduced this expression;

$$\mu = \frac{u}{E} = \frac{D\xi}{4\pi\eta} \qquad (6.1)$$

It was claimed by Smoluchowski that equation (6.1) was valid for rigid electrically insulated particles of any shape subject to these four restrictions(59).

a) That the usual hydrodynamical equations for the motion of a viscous fluid may be assumed to hold in the bulk of the liquid and within the double layer;

b) That the motion is streamline and slow enough for the inertia term in the hydrodynamic equation to be eliminated;

c) That the applied field may be taken as simply superimposed on the field due to the electrical double layer;

d) That the thickness of the electrical double layer is small compared with the radius of curvature at any point of the surface.

6.2.2 HÜCKEL'S EQUATION

Debye and Hückel(44) criticised Smoluchowski's equation by stating that while Smoluchowski's equation is valid for particles of any shape, subject to the four restrictions, the constant is not always equal to $\frac{1}{4\pi}$ but varies with the shape of the particle, and this constant could only be determined for each shape by the application of a detailed hydrodynamic analysis of the motion of the liquid. Hückel(136) has since published the constant to be $\frac{1}{6\pi}$ for a spherical particle. Therefore Hückel's equation is expressed as:

$$\mu = \frac{u}{E} = \frac{D\xi}{6\pi\eta} \qquad (6.2)$$

Debye and Hückel(44) also stated that the constant $\frac{1}{4\pi}$, could be used for particles of cylindrical shape.

Many authors including Hunter(4), Shaw(40) and Overbeek(56) have reviewed Hückel's equation. Shaw(40) found out that Hückel's equation is valid for small "ka" which is the ratio of the radius of curvature to the electrical double layer thickness and **is not** applicable to particle electrophoresis in aqueous media.

Debye and Hückel(44) used the same assumptions by Smoluchowski(135) but could not show where the analysis of Smoluchowski was not valid. There was then a contradiction which remained unsolved for several years until Henry(59) in a reviewed analysis of the whole problem reconciled the two contradictory points of view.

6.2.3 HENRY'S SOLUTION TO THE CONTRADICTION BETWEEN SMOLUCHOWSKI AND HÜCKEL THEORIES

The analysis carried out by Debye and Hückel(44) was examined by Henry(59) because the conclusion that the electrophoretic mobility of a particle should depend upon its shape appeared to be at variance with experimental facts.

Henry(59) found out that Debye and Hückel assumed the applied potential gradient to be parallel to the x-axis everywhere and to be undisturbed by the presence of the particle, but this would only be the case if the electrical conductivity of the particle is identical with that of the medium which would seldom occur in practice. But Smoluchowski (135) considered an insulating particle and therefore took the deformation of the applied electrical field by the insulating particle explicity into account. Hence the difference between the concepts of Smoluchowski(135) and Debye and Hückel(44) is the geometry of the applied electrical field. The conception of Debye and Hückel is quite justified in using electrolytic solutions since the extension of the electrical double layer is so much larger than the dimensions of the ions that the deformation of the field which is only felt in the immediate vicinity of the ions is practically without the influence upon electrophoretic retardation(56).

Henry(59) employed the same analytical methods as Hückel but using a particle of different specific electrical conductivity from that of the medium. This method was applied to spheres and cylinders in both axial and tranverse positions and the results obtained when subjected to Smoluchowski's four restrictions, then equation (6.1) is valid in each case and hence Henry derived the following for both insulating sphere and a cylinder which agreed with Smoluchowski

$$\mu = \frac{u}{E} = \frac{D\xi}{4\pi\eta} \qquad (6.3)$$

In deducing his equation (6.3) Henry found out that the deformation of the applied electrical field is strongly dependent on the electrical conductance of the particle. This deformation and its influence upon the electrophoretic mobility is determined by the ratio of the electrical conductivities of the particle to the surrounding liquid.

Shaw(40) has discussed the general electrophoretic equation which Henry derived for both conducting and non-conducting spheres which takes the form,

$$\mu = \frac{u}{E} = \frac{D\xi}{6\pi\eta} \left[1 + \lambda F(ka) \right] \qquad (6.4)$$

where F(ka) varies between zero for small values of ka and 1.0 for large values of ka and

$$\lambda = \frac{k_o - k_1}{2k_o + k_1} \qquad (6.4.1)$$

where k_o is the specific conductance of the bulk electrolyte solution and k_1 is the specific conductance of the particles.

For non-conducting particles, $\lambda = 0.5$, and equation (6.4) can then be expressed as

$$\mu = \frac{u}{E} = \frac{D\xi}{6\pi\eta} f(ka) \qquad (6.5)$$

where f(ka) varies between 1.0 for small particles (Hückel's equation) and 1.5 for large ka (Smoluchowski's equation)

Therefore the zeta potential calculated using the Hückel for ka = 0.5 and from the Smoluchowski equation for ka = 300 differ about one per cent from the corresponding zeta potentials which have been calculated using the Henry equation. It should also be noted that Henry's equation is based on these assumptions:-

- (a) Debye - Hückel approximation is applied;
- (b) applied field and the field of the electrical double layer are simply superimposed, because the mutual distortion of these fields could affect the electrophoretic mobility;-
  - (i) through abnormal conductance (surface conductance) in the neighbourhood of the charged surface;
  - (ii) through loss of the double layer symmetry (relaxation effect)
- (c) the dielectric constant and viscosity were assumed to be constant throughout the mobile part of the double layer.

For low values of ka (small spheres) Hückel's equation is valid and for large spheres the Smoluchowski's equation is then valid.

6.3 CONDUCTION EFFECTS IN ELECTROPHORESIS

The conduction effects in electrophoresis can be attributed to :-

- a) The particle conductance and shape,
- b) Surface conductance.

The effect of the conductivity of the particle determines how the presence of the particle distorts the applied electrical field. Henry(59) has considered the spheres of different conductivity and established a relation as expressed in equation (6.4). For a highly conducting sphere the behaviour is unaffected for ka $\leqslant$ 1, since the effect of deformation of the field is only important if electrophoretic retardation is important and it is not for ka $\leqslant$ 1. As ka increases and electrophoretic retardation becomes more significant, the electrophoretic mobility decreases until ultimately at very large ka, it falls to zero. It is doubtful when in any ordinary circumstances there is any need to take into account, the effects of high particle conductivity(4). Even metallic dispersion appears to exhibit normal electrophoretic behaviour which Overbeek(9) attributes to the effects of polarisation. Unless there is evidence to the contrary, then all particles may be treated as insulators with the exception of liquid metallic dispersion(4).

The distribution of ions in the diffuse part of the electrical double layer gives rise to an electrical conductance in this region which is in excess of that in the bulk electrolyte medium. Surface conductance will affect the distribution of the electrical field near to the surface of a charged particle and so influence its electrokinetic behaviour(40). The effect of surface conductance on the electrophoretic behaviour can be neglected when 'ka' is small because the applied electrical field is hardly affected by the particle size in any case. When "ka" is not small, the calculated zeta potential may be significantly low on account of surface conductance.

Shaw(40) has discussed the Booth and Henry equation which relates electrophoretic mobility with the zeta potential for non-conducting spheres with large "ka" and when corrected for surface conductance can be expressed as:-

$$\mu = \frac{u}{E} = \frac{D\xi}{4\pi\eta}\left[\frac{k_o}{k_o + \frac{k_s}{a}}\right] \qquad (6.6)$$

where k_s is the specific conductance.

Experimental surface conductances which are not very reliable tend to be higher than those calculated for the mobile part of the electrical double and the possibility of surface conductance inside the shear plane(9). There is therefore some uncertainty regarding the influence of surface conductance on electrophoretic behaviour.

The expression established by Henry in equation (6.6) is seldom used because the modern theory of electrophoresis takes the surface conductance into account by dealing explicitly with the electrophoretic mobility of the electrical double layer ions. Provided the surface conductivity is normal (equal to what would be expected from the known concentrations and mobilities of ions in the double layer) its effects are taken into account in the treatment of the relaxation effect(4).

6.4 THE INFLUENCE OF THE DEFORMATION OF THE ELECTRICAL DOUBLE LAYER UPON ELECTROPHORESIS

The effect of relaxation arising from the deformation of the electrical double has a retarding influence on electrophoresis(4,19,26,56,124). In an applied electrical field the charge of the diffuse double layer is displaced in a direction opposite to the movement of the particle and this does not only retard the electrophoresis by its movement but also by the resulting dissymetry of the double layer sets up a retarding potential difference. Corrections have been suggested by several authors including Overbeek(9) and Booth(138).

In the stationary state which is reached shortly after the electrical field is applied in electrophoresis, the particles move with a constant velocity and the total force on the particles is zero. Therefore in the first approximation the electrical force on the charged particle is equal to the hydrodynamic frictional force on the particle by the liquid. A detailed analysis of the problem illustrate that two additional forces oppose the electrical forces namely(4,10,26,56,):-

a) An additional frictional force results from the movement of water with counter ions which move in a direction opposite to that of the particle. This force is known as the electrophoretic retardation force.

b) A second retarding force is caused by a distortion of the diffuse atmosphere of counter-ions around the particle. This force is called the relaxation force.

Since the counter-ions move in an opposite direction, the electrical double layer in front of the particle must be constantly restored as it is broken off behind the particle. The restoration of the double layer takes a finite time known as the relaxation time. Therefore the electrical double layer will be shifted somewhat with respect to the particle and will exert an electric retardation force.

The complete formula relating the electrophoretic mobility and the zeta potential is derived by the theoretical evaluation of the four forces acting on the particles. These four forces are namely:-

a) electrical force on the charged particle,
b) hydrodynamic frictional force on the particle by the liquid,
c) electrophoretic retardation force,
d) relaxation force.

Since such an evaluation is possible only for limited cases no formula is available which covers every situation (26).

6.4.1 EFFECT OF ELECTROPHORETIC RETARDATION

The action of the electrical field on the double layer ions which causes the liquid to move is called the electrophoretic retardation because this action causes a reduction in the velocity of the migrating particle.

Smoluchowski's$^{(135)}$ treatment assumed that this was the dominant force and that the particle's motion was equal and opposite to the liquid motion.

Hückel$^{(136)}$ on the other hand, made proper allowance for the electrophoretic retardation in his analysis. It turns out, however that his equation is valid for small values of 'ka' when electrophoretic retardation of the particle is relatively unimportant and the main retarding force is the frictional resistance of the medium.

Dukhin and Derjaguin$^{(139)}$ showed that the ratio of the retardation force to the viscous resistance is of the order 'ka'. Therefore for small particles, although the retardation force acts across the whole double layer, very little of it is transmitted to the particle.

The electrophoretic retardation remains important in the description of electrolytic conduction where "ka" is very small and could be attributed to:-

a) the movement of ions of both positive and negative signs,

b) the calculation of the interaction effects for large number of ions.

For large particles with double layers essentially all of the electrophoretic retardation is communicated directly to the particle(139).

In conductance of strong electrolytes the influence of the relaxation effect is of the same order of magnitude as the retardation caused by the motion of the ions of the atmosphere, and therefore in order to arrive at a complete description of electrophoresis, it is necessary to include the relaxation effect.

6.4.2 RELAXATION EFFECT

The calculations made by Henry(59) were based on the assumption that the external field could be superimposed on the field due to the particle and that the latter could be described by linearized version of the Poisson-Boltzmann equation. Certainly this is not exactly the case, as the particle and the outer part of the electrical double layer having opposite signs of charge, move in opposite directions by which means the original symmetry of the double layer is disturbed(56).

The movement of the particle relative to the mobile point of the double layer results in the double layer being distorted because a finite time known as relaxation time, is required for the original symmetry to be restored by diffusion and conduction(4,40,56). The outer part of the double layer then lags behind the particle. The resulting assymetric ionic atmosphere exerts an additional retarding force on the particle which is known as the relaxation effect and this is not accounted for in the Henry equation (6.4). Relaxation can be safely neglected for both small and large values of "ka" ($ka < 0.1$ and $ka > 300$) but it is significant for the intermediate values of "Ka", especially at high potentials and when the counter ions are polyvalent and, or have low mobilities(40,56).

Overbeek(56) and Booth(140) derived equations for spherical particles which allow for retardation, relaxation, and surface conductance in the mobile part of the double layer and which expressed electrophoretic mobility as a power series. Due to mathematical difficulties these equations were only solved for a restricted number of terms. At higher potentials the relaxation effect was overestimated.

The treatments of Overbeek(56) and Booth(140) have now been superseded both in the range of validity and convenience by that of Wiersema et al(137), in which the appropriate differential equations have been solved without approximation using an electronic computer. The main assumptions applied are:-

a) The particle is a rigid, non-conducting sphere with its charge uniformly distributed over the surface,

b) The electrophoretic behaviour of the particle is not influenced by other particles in the dispersion,

c) Dielectric constant and viscosity are constant throughout the mobile part of the double layer,

d) Only one type of each positive and negative ions are present in the electrical double layer.

Overbeek(9) pointed out that, inter alia, the relaxation effect may give important corrections if the zeta potential is not very small for values from 0.1 to 100. This therefore means that, very often conclusions as to the value of the zeta potential derived from the electrophoretic measurements are open to serious doubt.

6.5 DIELECTRIC CONSTANT AND VISCOSITY

In the calculation and interpretation of the zeta potential there arises further difficulty if the electrical field strength which is close to the shear plane is high enough to significantly decrease the dielectric constant and increase the viscosity by dipole orientation(11,40,61,62,137,140,141,142).

Lyklema et al(61) examined the variability of the dielectric constant and viscosity in the electrical double layer and carried out correction of the Helmholtz-Smoluchowski equation for the variability of the viscosity. The dielectric constant in the inner region was deduced from the double layer capacity evidence to be smaller than that of the bulk liquid. This is due to the saturation effects caused by the high field strengths in the double layer and to the structural influence of the adjacent phase. Lyklema et al(61) however concluded that it is mostly justified to use the bulk value of the dielectric constant in the electrophoresis equation of Helmholtz-Smoluchowski, but in all cases the viscosity was determined to increase with the electrical field strength.

A significant and positive visco-electric effect would result in the effective location of the shear plane moving away from the particle surface which would result in increasing the zeta potential and or increasing the thickness of the electrical double layer(4,40,141,142). Therefore the zeta potential would vary and not be constant.

Recent investigations by Hunter(4,62) suggest, however, that the viscoelectric effect was overestimated by Lyklema et al(61) and that is significant in most practical situations. Hunter(62) also reviewed the influence of viscosity on the zeta potential, variation of the dielectric constant (permittivity) with field strength, and influence of surface charge density on the position of shear plane.

RESULTS AND DISCUSSION

CHAPTER 7

7.1 INTRODUCTION

Most suspended particles in water are charged and the electrical repulsion between them tends to prevent aggregation. Many additives can reduce the particle charge and hence cause destabilization of the suspended particles. In such cases, the measurement of the particle charge as a function of the reagent dosage can give a good indication of the optimum condition The most common approach is to measure the zeta potential of the particles.

There are several reports in the literature(4,7,10,30, 69,73,76) indicating that the zeta potential is a useful means of controlling practical flocculation processes. While this seems reasonable in certain cases, there are other cases where the relationship between the zeta potential and colloid stability is not so straight-forward.

The nature of the charge or charges on the colliery fines were determined and also the electrophoretic mobility which was used to calculate the zeta potential. The point of zero charge (zpc) and the iso-electric point (iep) were also determined.

The pH value at which the zeta potential could be reduced to, in order to carry out the flocculation of the colliery waste-water was also carried out. Finally the optical densities were also determined after flocculation.

The microscope was focussed at different levels of depth in the electrophoretic cell and the time taken for the particles to move through the distance was measured.

These measurements were taken in one direction and then the voltage was reversed (circuit reversed) so that the particles could be timed in the reverse direction (opposite direction).

The detailed results have been tabulated in the appendices B, C, and D.

7.2 ELECTROPHORESIS OF 100 ppm QUARTZ SUSPENSION

The validity of the experimental set-up was confirmed by the determination of the nature of charge, electrophoretic mobility and the zero point of charge of quartz.

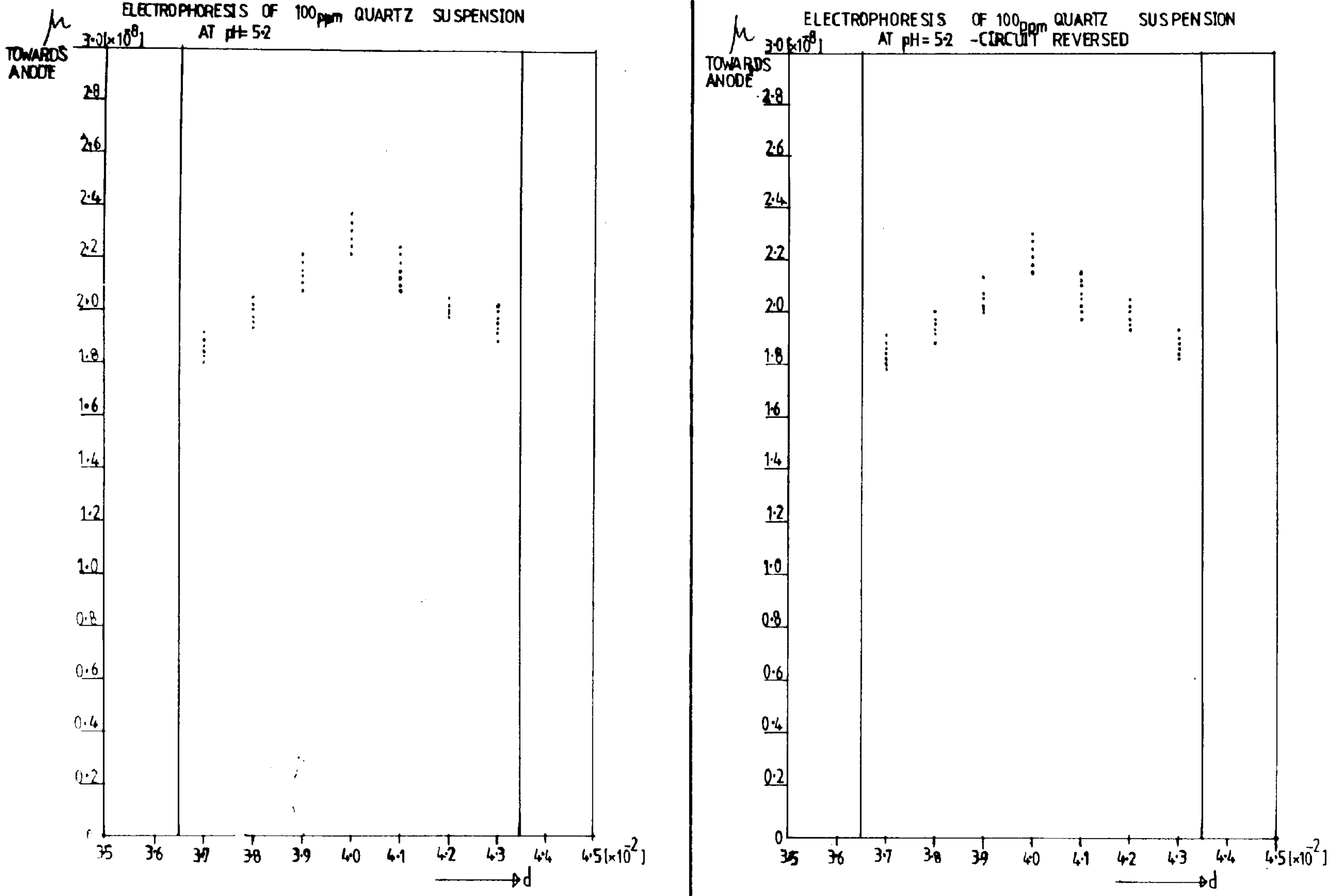
The quartz particles were determined to be negatively charged and this agreed with the work of Bhappu and Deju(128) and Hunter(4).

The graphs of the mobility profile at different pH values against the various levels of cell depth within the electrophoretic cell compared favourably with those obtained by Hunter(4) Shergold et al(129) and Prasad(70). These graphs can be seen in Figures 7.1 to 7.6. At a particular cell depth there were obtained different electrophoretic mobilities of the particles. This could be explained by the fact that there were different particle sizes in the 100ppm quartz suspension.

The graphs of the mobility profile at the same depth but against different pH values can be seen in Figures 7.7 to 7.13. It can be seen on these graphs that between the pH values of 5.6 and 4.0, all the quartz particles moved towards the anode, between 4.0 and 3.8 some moved towards the anode and some towards the cathode, and at pH values less than 3.8 the particles moved towards the cathode.

The point of zero charge was determined to be at the pH value of 3.8 which compared favourably with the values obtained by Hunter(4) and Bhappu and Deju(128).

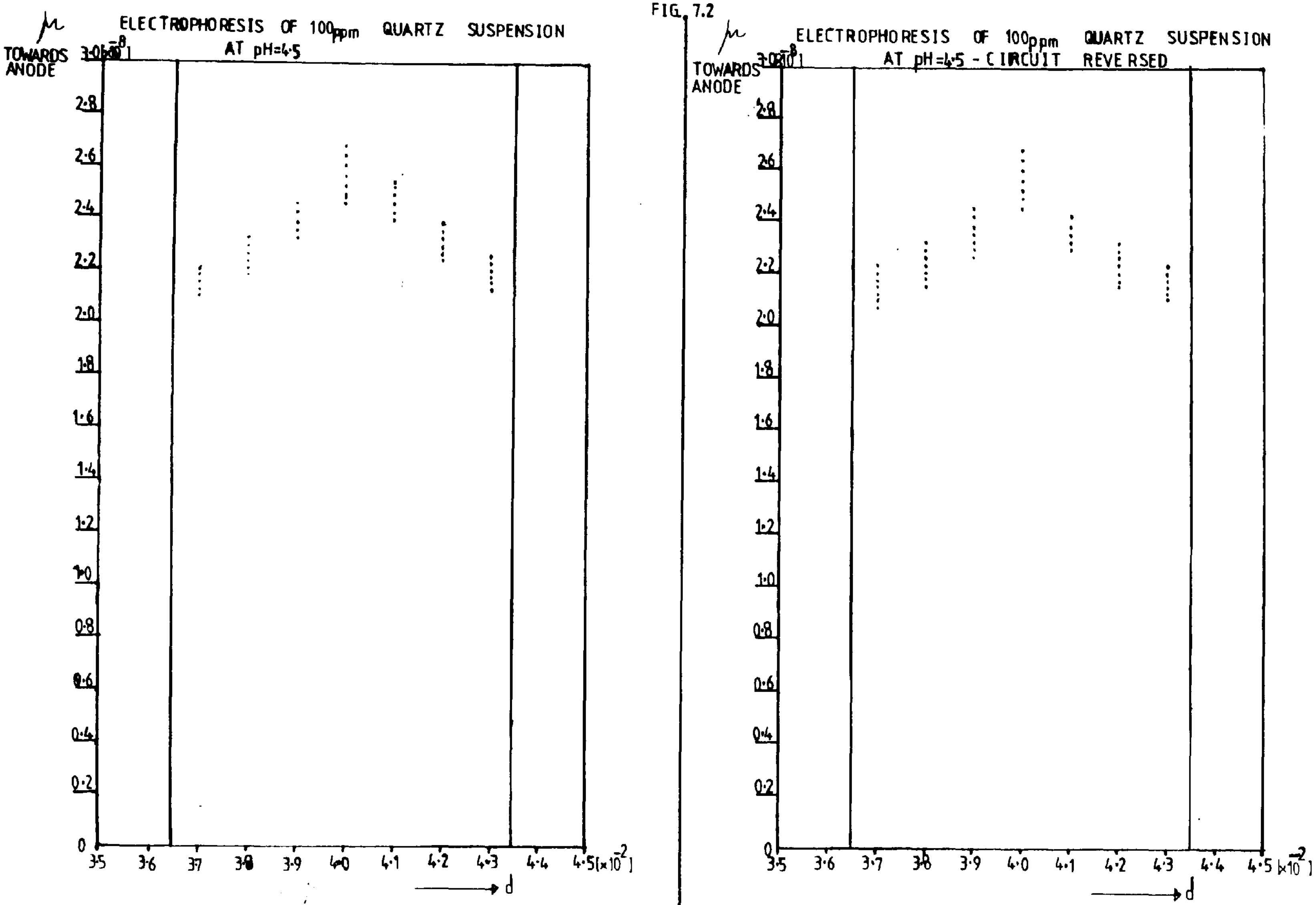
FIG. 7.1



ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 5·2

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 5·2 -CIRCUIT REVERSED

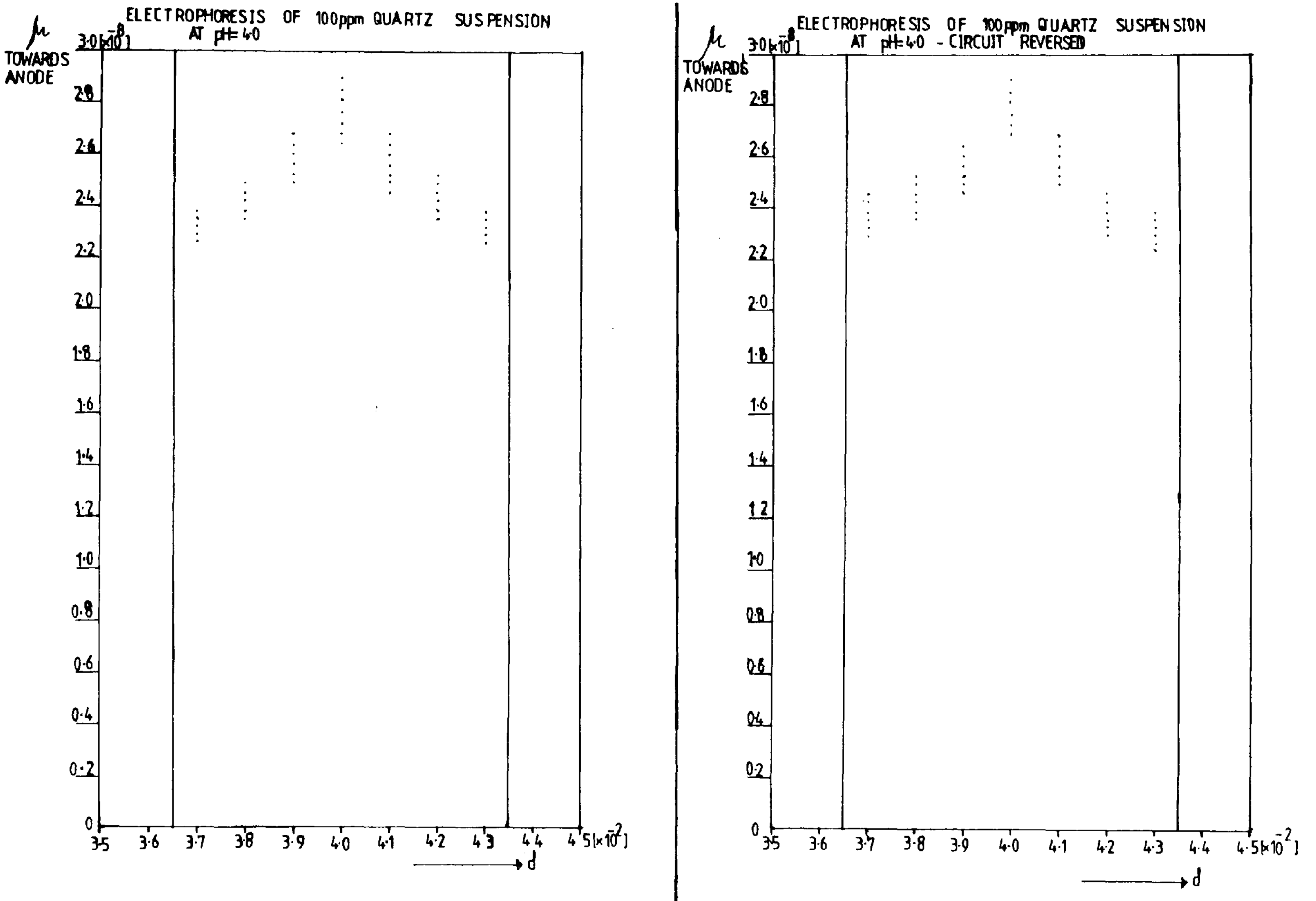
FIG. 7.2



ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=4·5

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=4·5 - CIRCUIT REVERSED

FIGURE. 7.3



ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=4·0

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=4·0 - CIRCUIT REVERSED

FIGURE. 7.4

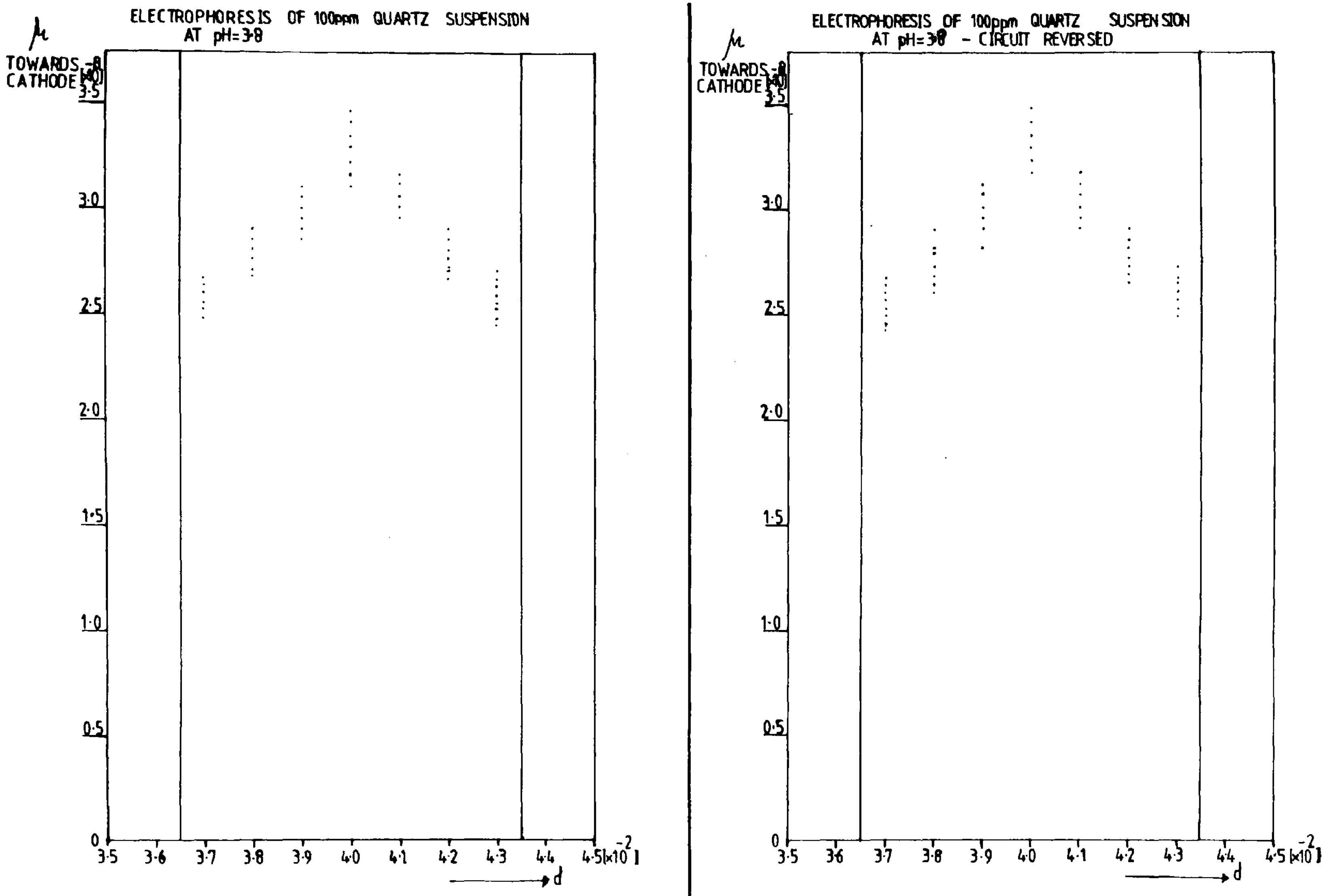
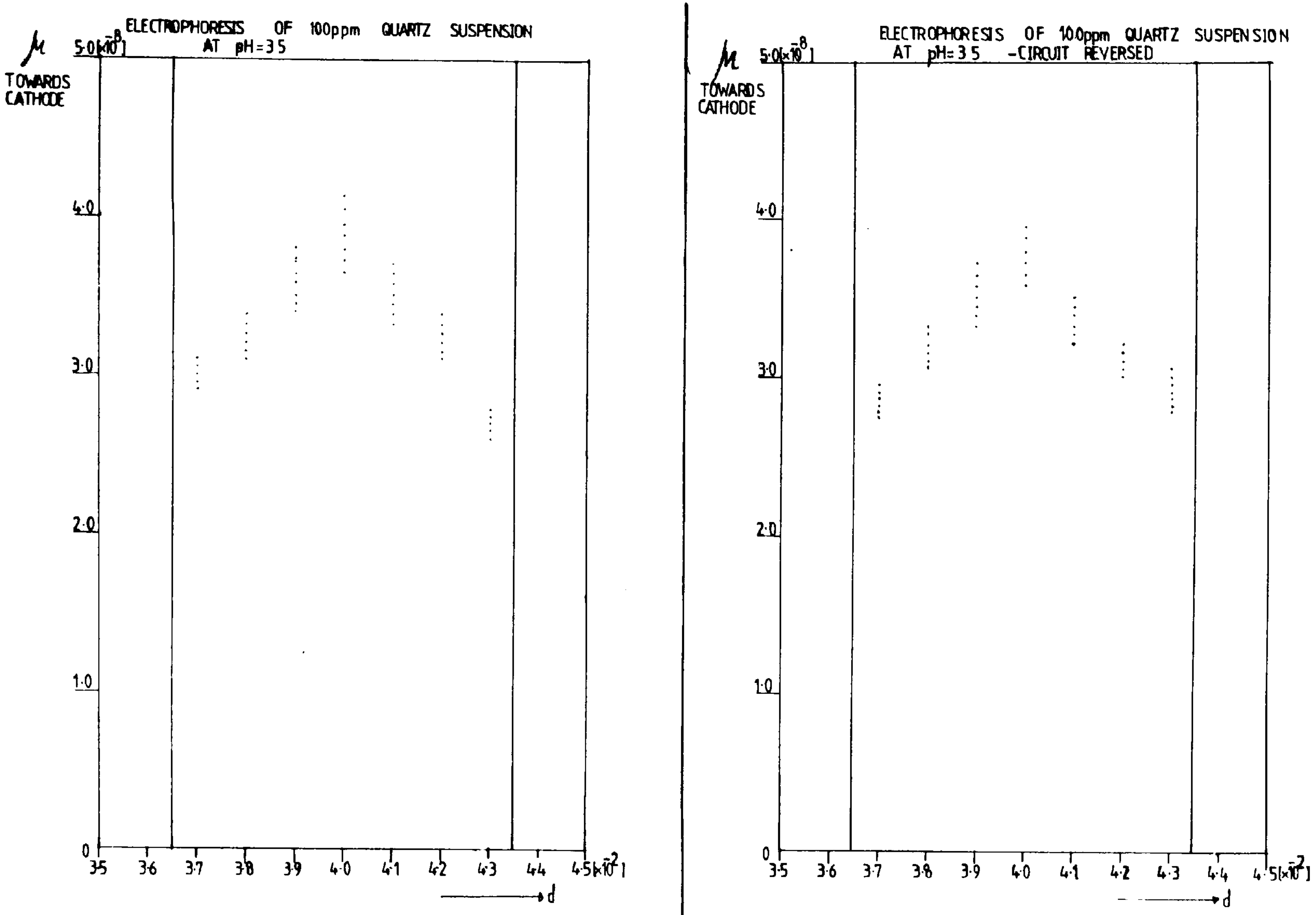

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=3·8
μ TOWARDS CATHODE [x10^-8]
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
3·5 3·6 3·7 3·8 3·9 4·0 4·1 4·2 4·3 4·4 4·5 [x10^-2]
d
ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=3·8 - CIRCUIT REVERSED
μ TOWARDS CATHODE [x10^-8]
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
3·5 3·6 3·7 3·8 3·9 4·0 4·1 4·2 4·3 4·4 4·5 [x10^-2]
d

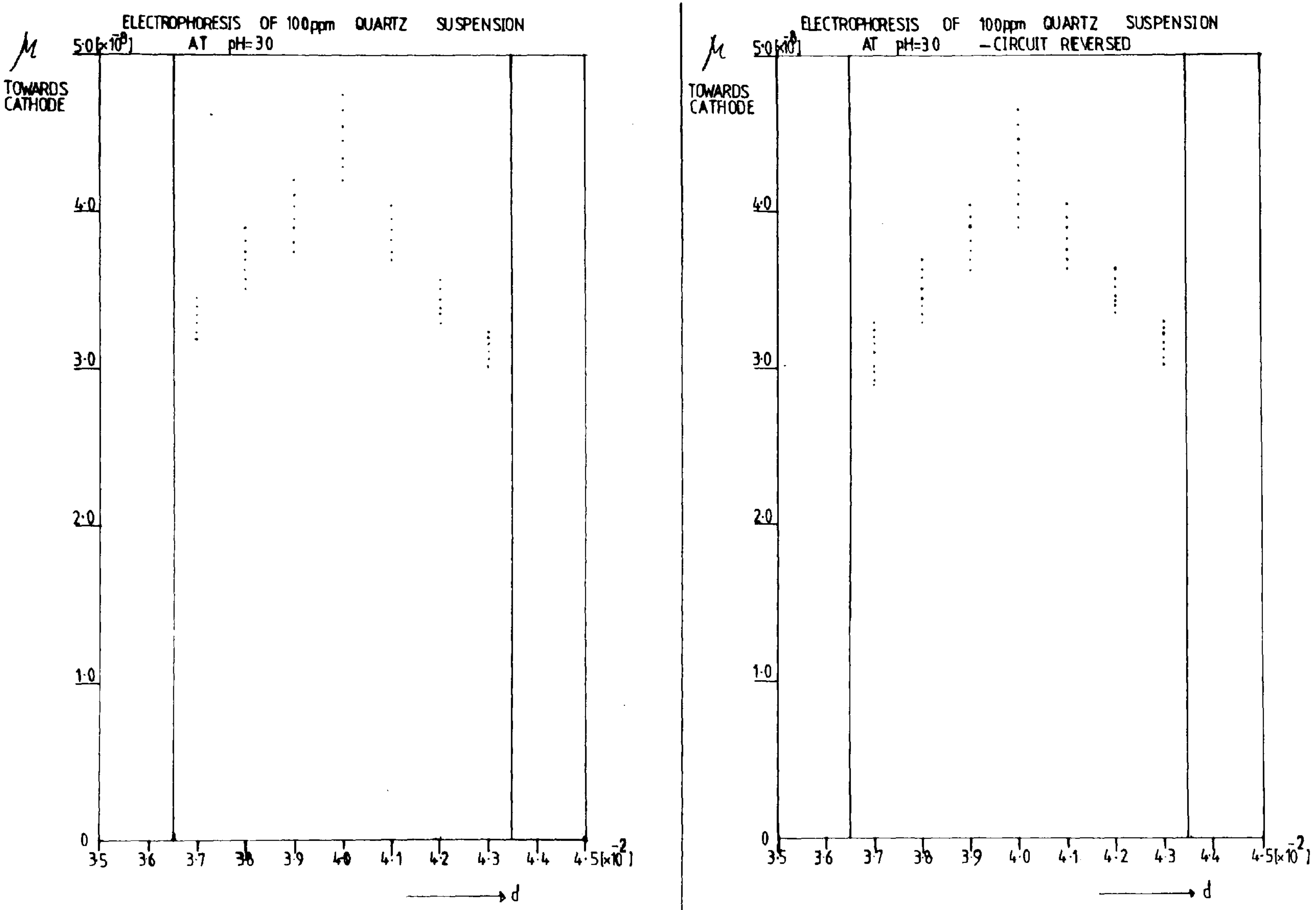
FIGURE. 7.5



ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=3.5

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=3.5 -CIRCUIT REVERSED

FIGURE. 7.6

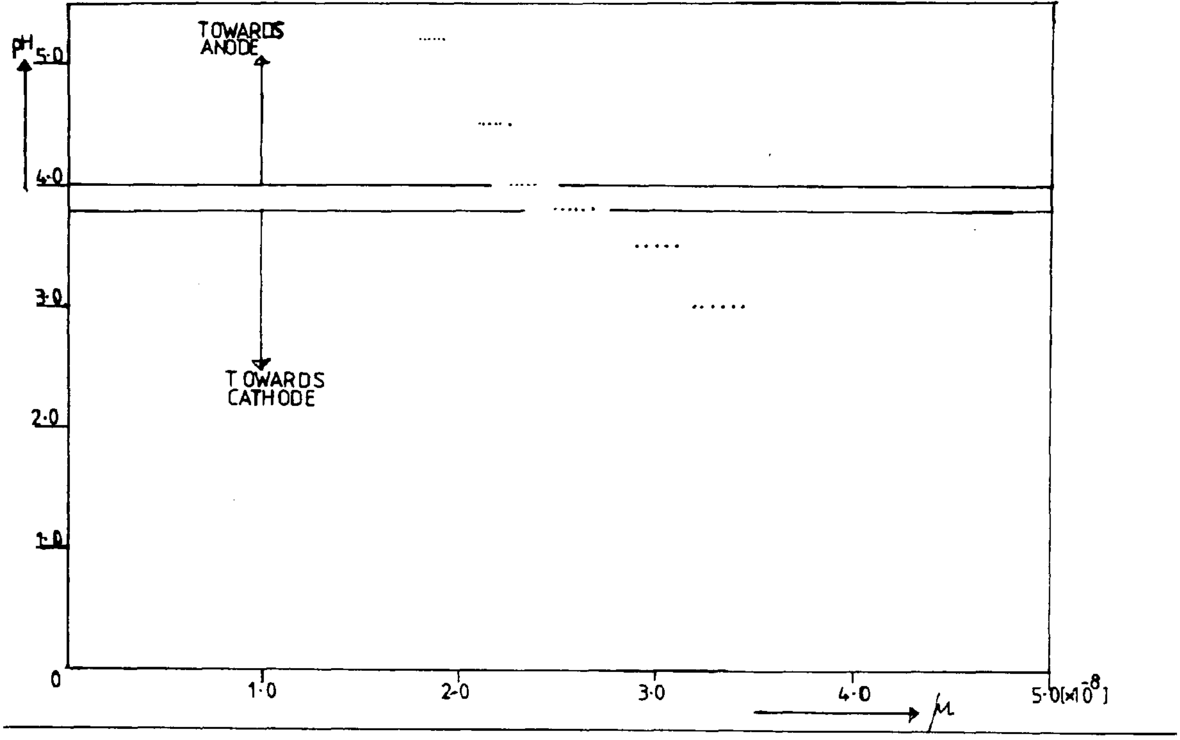


ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=30

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH=30 –CIRCUIT REVERSED

FIGURE. 7.7

VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3.70 \cdot 10^{-2}$ m



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3.80 \cdot 10^{-2}$ m

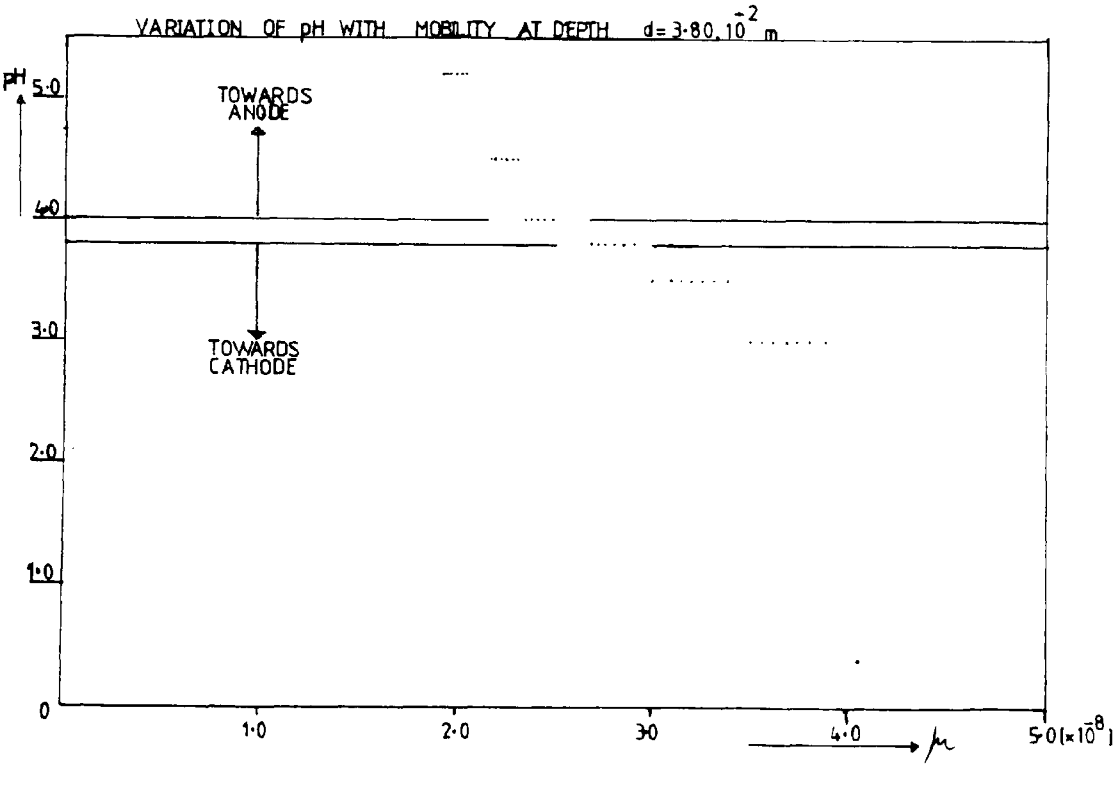
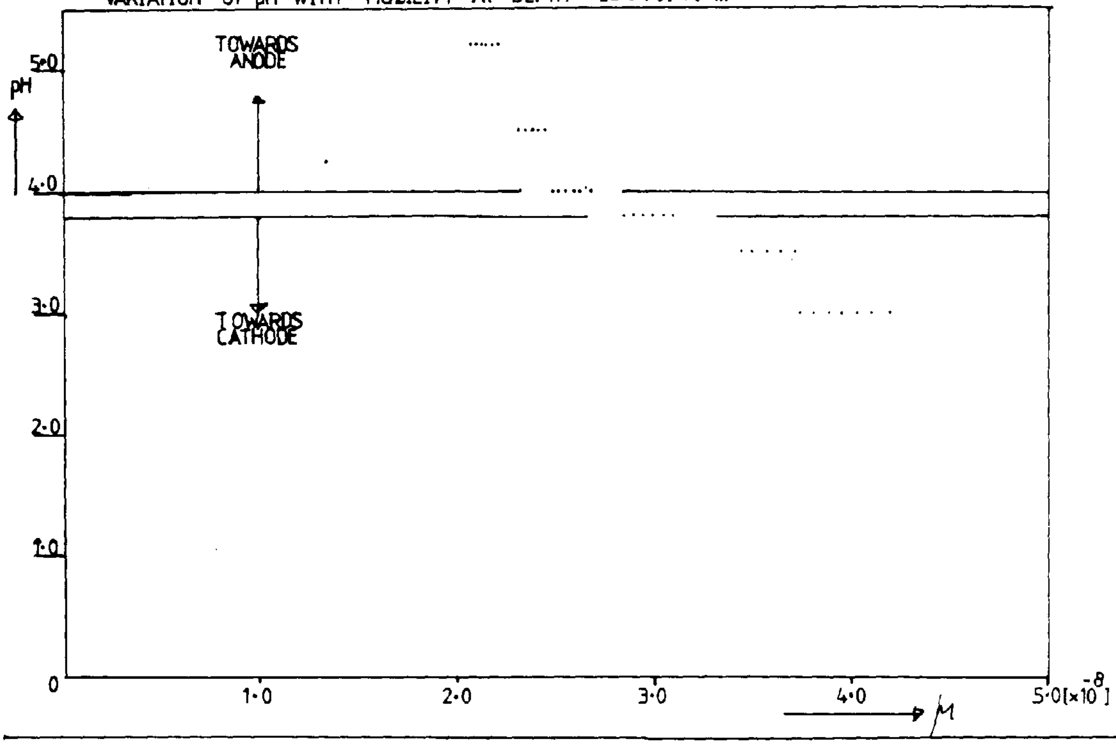


FIGURE. 7.8

VARIATION OF pH WITH MOBILITY AT DEPTH d= 3·90. 10^{-2} m



VARIATION OF pH WITH MOBILITY AT DEPTH d=4·0 . 10^{-2} m

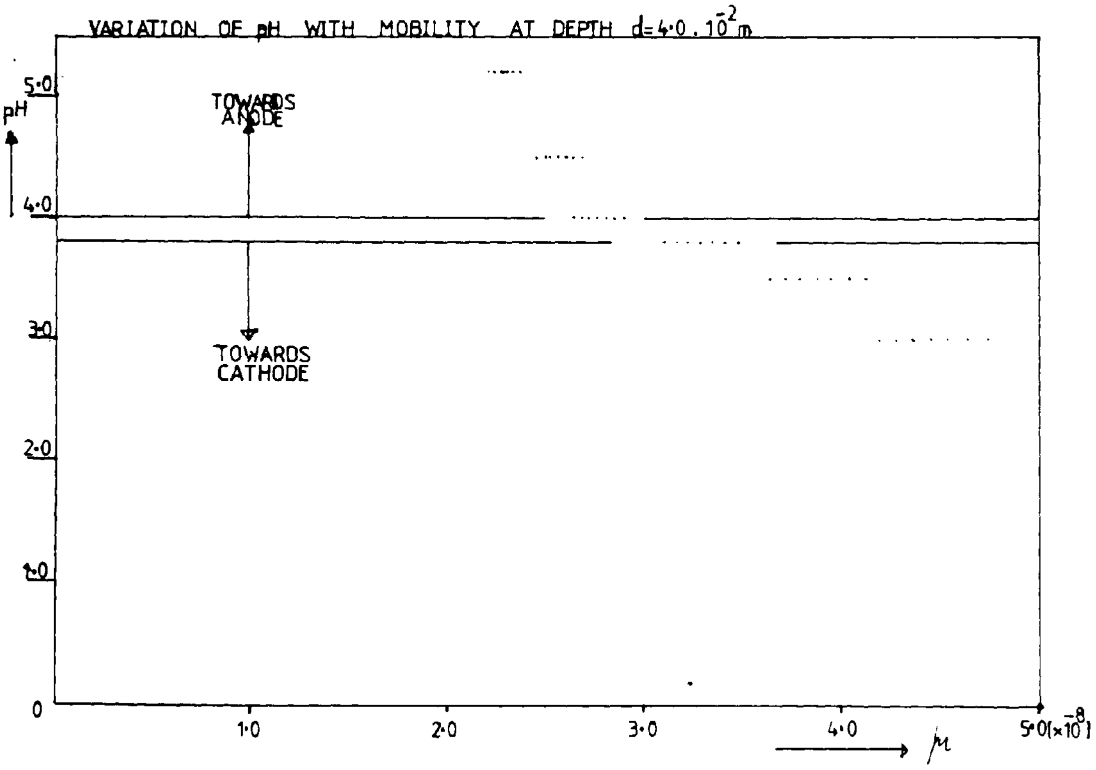
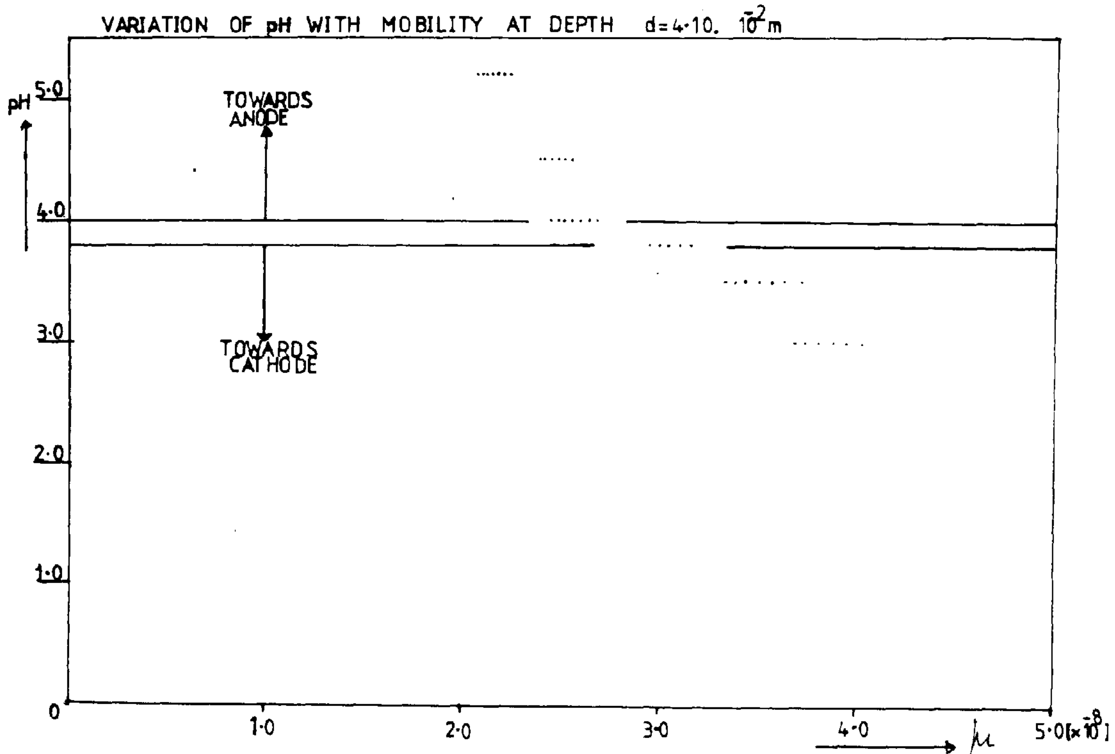


FIGURE. 7.9


VARIATION OF pH WITH MOBILITY AT DEPTH d=4·10. 10^{-2}m
pH
5·0
4·0
3·0
2·0
1·0
0
TOWARDS ANODE
TOWARDS CATHODE
1·0
2·0
3·0
4·0
5·0[×10^{-8}]
μ

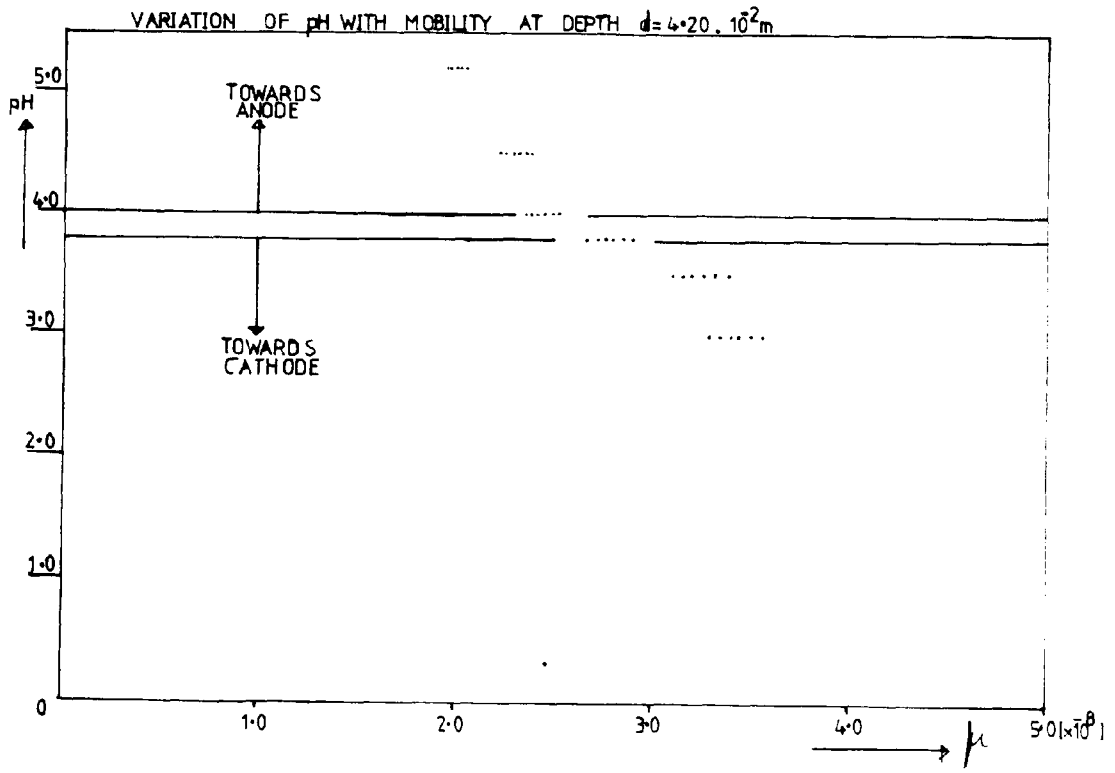
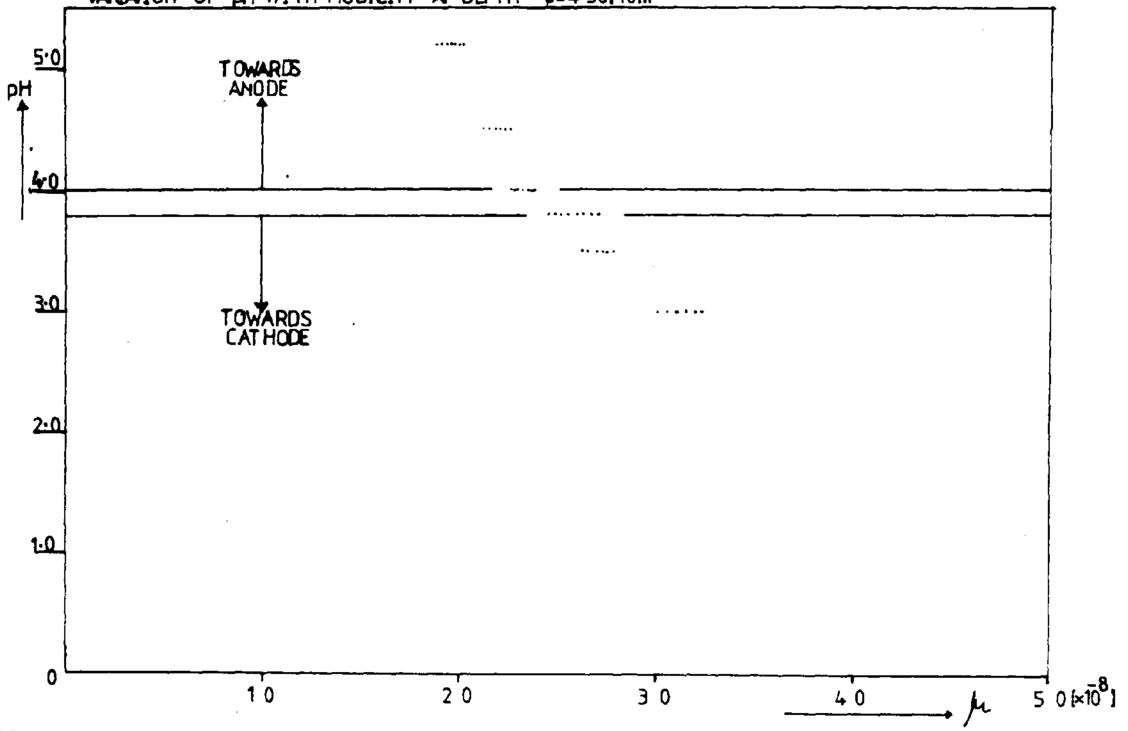

VARIATION OF pH WITH MOBILITY AT DEPTH d=4·20. 10^{-2}m
pH
5·0
4·0
3·0
2·0
1·0
0
TOWARDS ANODE
TOWARDS CATHODE
1·0
2·0
3·0
4·0
5·0[×10^{-8}]
μ

FIGURE. 7.10


VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}30.10^{-2}m$

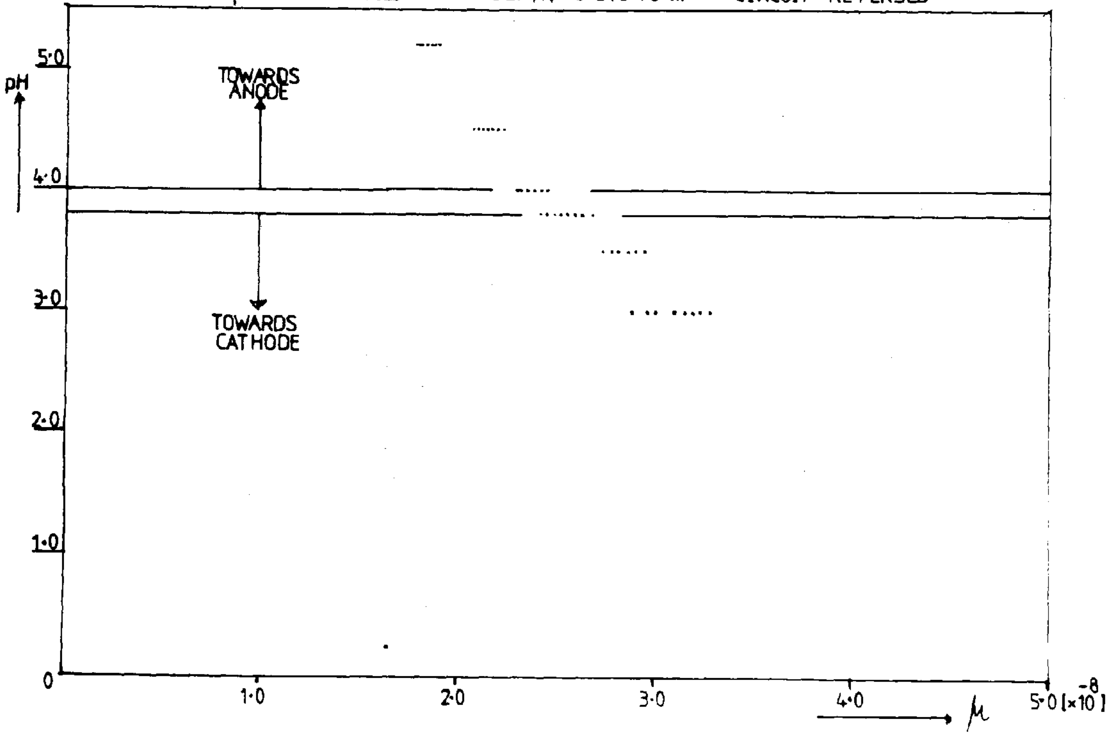
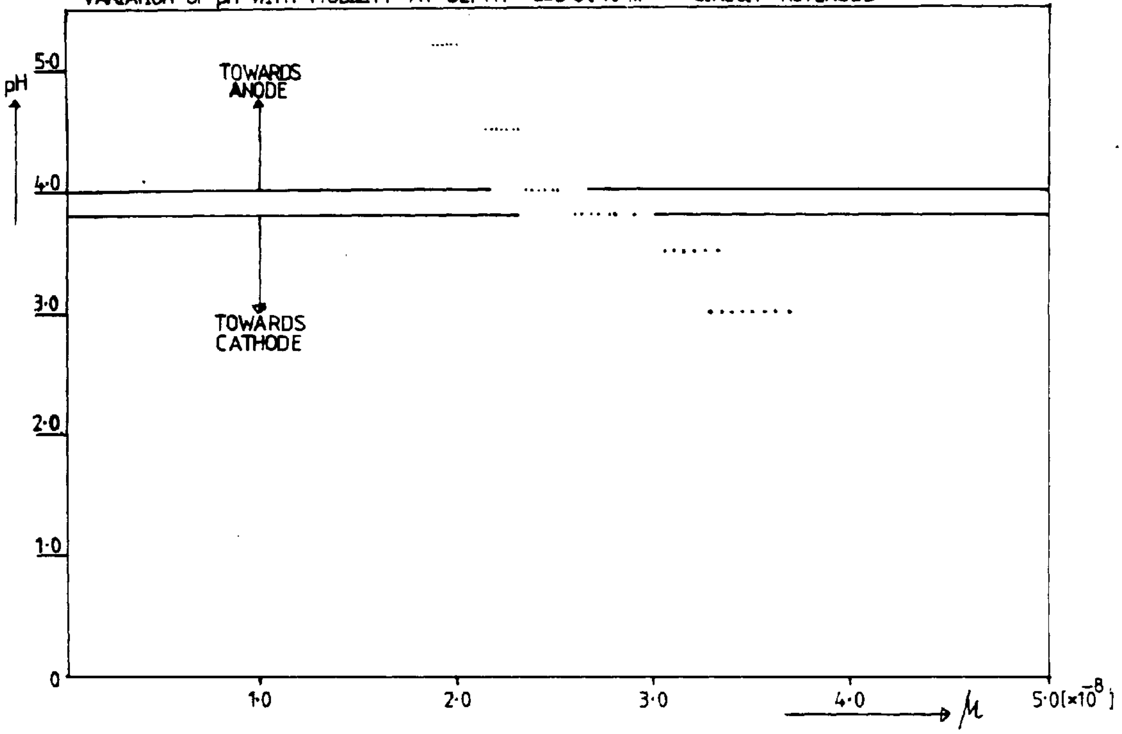

VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}70\ 10^{-2}m$ — CIRCUIT REVERSED

FIGURE. 7.11

VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}8 . 10^{-2}m$ — CIRCUIT REVERSED



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}9 . 10^{-2}m$ — CIRCUIT REVERSED

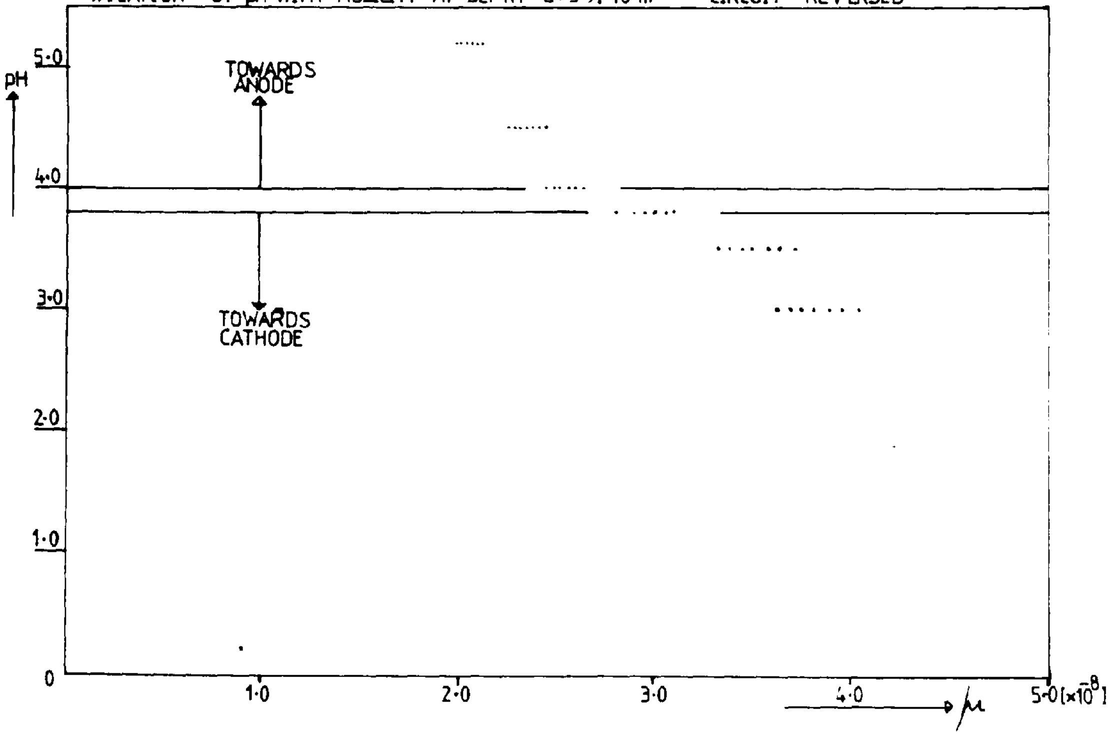
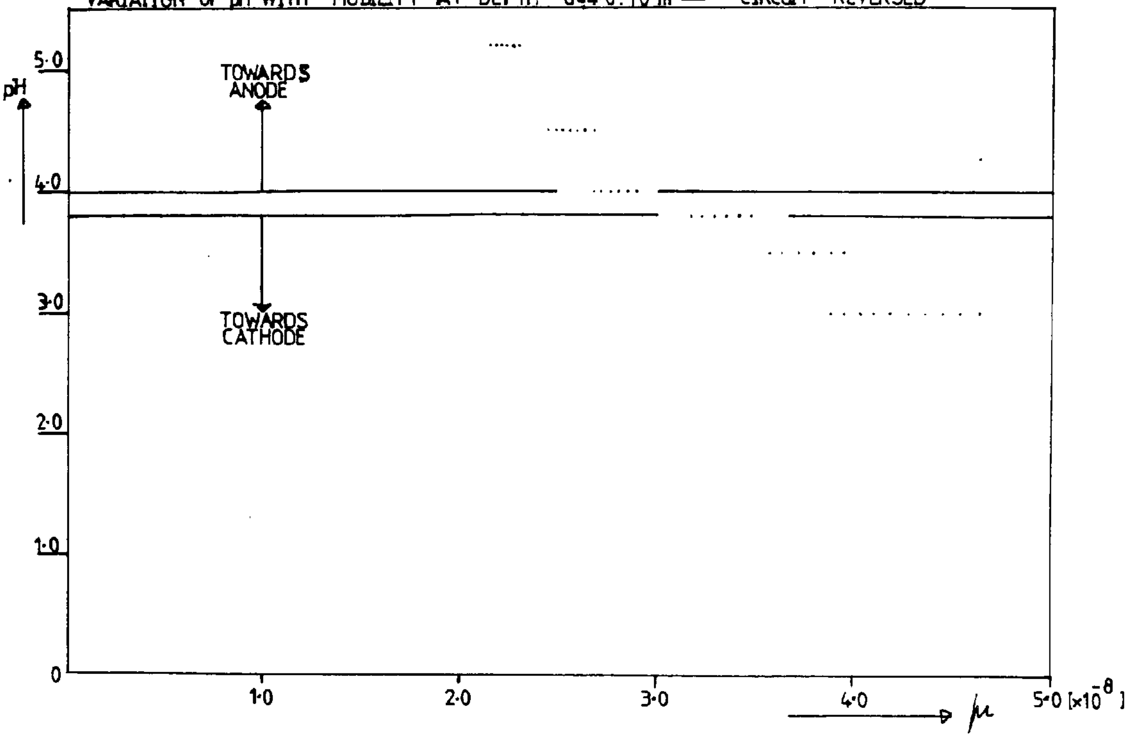


FIGURE. 7 12.

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}0.10^{-2}m$ — CIRCUIT REVERSED



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}10.\ 10^{-2}m$ — CIRCUIT REVERSED

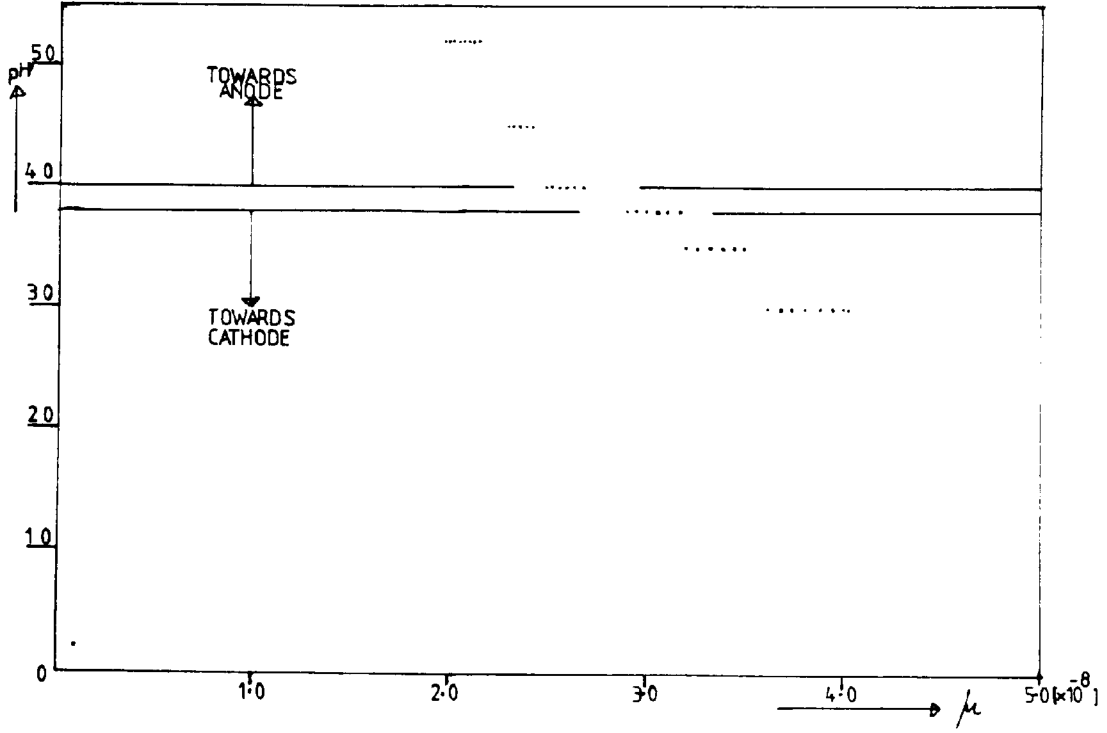
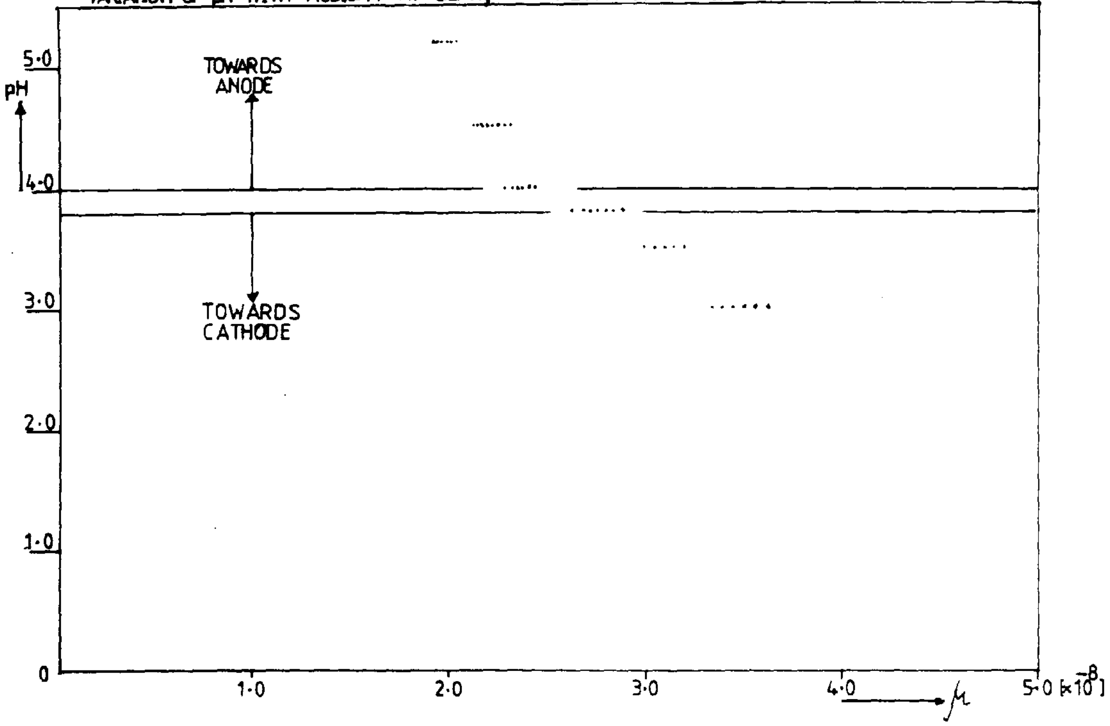
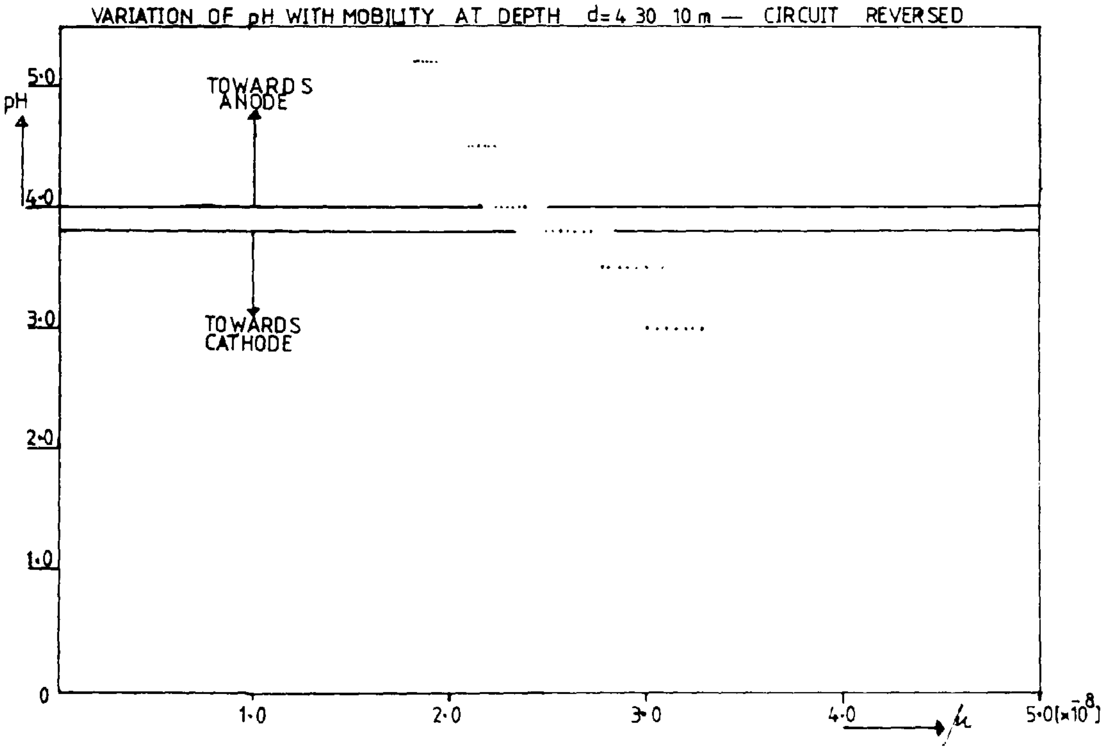


FIGURE.7. 13

VARIATION OF pH WITH MOBILITY AT DEPTH d = 4·20. 10^{-2}m — CIRCUIT REVERSED



VARIATION OF pH WITH MOBILITY AT DEPTH d=4 30 10 m — CIRCUIT REVERSED



7.3 ELECTROPHORESIS OF COLLIERY WASTE-WATER - (HCl)

The origin of the surface charge which forms on the minerals immersed in water is very important in mineral processing since a large amount of the flotation, rheological and flocculation (aggregation) of the mineral pulps is influenced by this charge. Much of the charging mechanism at the mineral - water interface has been developed from the results of the electrokinetic measurements of the zero point of charge. The different pH values were obtained by the addition of hydrochloric acid.

The charges on the fines in the colliery waste-water were determined to be both positive and negative as can be seen in the mobility profile at the various pH values against the different levels of cell depth within the electrophoretic cell. (Figures 7.14 to 7.23)

On viewing these fines under the microscope these coal particles appeared to be coated, and this was further confirmed by scanning electron microscopy. They were also found to be aluminium silicates from x-ray crystallography. The coating on the coal particles were determined to be a layer of aluminium silicates which are basically colloidal clay particles, the hydrophilic nature of which is able to prevent the attachment of an air bubble to the hydrophobic coal surface.

Slime particles of near colloidal size are able to coat coal particles in flotation pulp. It should be remarked here that the National Coal Board uses the Froth Flotation reagent of twenty five per cent Tar acids in gas oils. Hence coating could occur whenever the particles carry charges of opposite sign or small charges of the same sign, or in some instances when the particles of one species carry a large charge and these of a second species carry a very small charge. The magnitude of the charge is measured in terms of the zeta potential(144).

It would seem unlikely for a clay slime which is negatively charged to coat the surface of a coal particle carrying quite a high potential of the same sign. However, Van Olphen(26) observed that sub-micro-scopic particles of montmorrilonite clays exist as thin platelets and from experimental evidence he concluded that they carry a dual electrical charge. Hence the dual charge on the fines in colliery waste-water appears to be due to the imperfections in the silicate crystal lattice structure in which the flat surfaces are negatively charged whilst the exposure of alumina along the edges of the platelet is responsible for the positive charge.

It could be possible that the positively charged edges of the clay particles would be attracted by the negatively charged coal surfaces so that the clay particles would become oriented perpendicularly to the surface, and thus being more remote, the negative charges on the flat clay surfaces exercises less repulsion and equilibrium may be possible.

Several investigators(145,146,147) have indicated that positive sites exist on the edges of clay crystals owing to the exposed lattice aluminium atoms at the locations. Consequently clay particles possess two oppositely charged double layers, one associated with the face of the clay plates and the other associated with the edges of the plates.

The graphs of the mobility at different pH values on using hydrochloric acid against the various levels of cell depth compared favourably with each other with the reversal of charge occuring at pH value of 4.9.

FIGURE. 7.14.

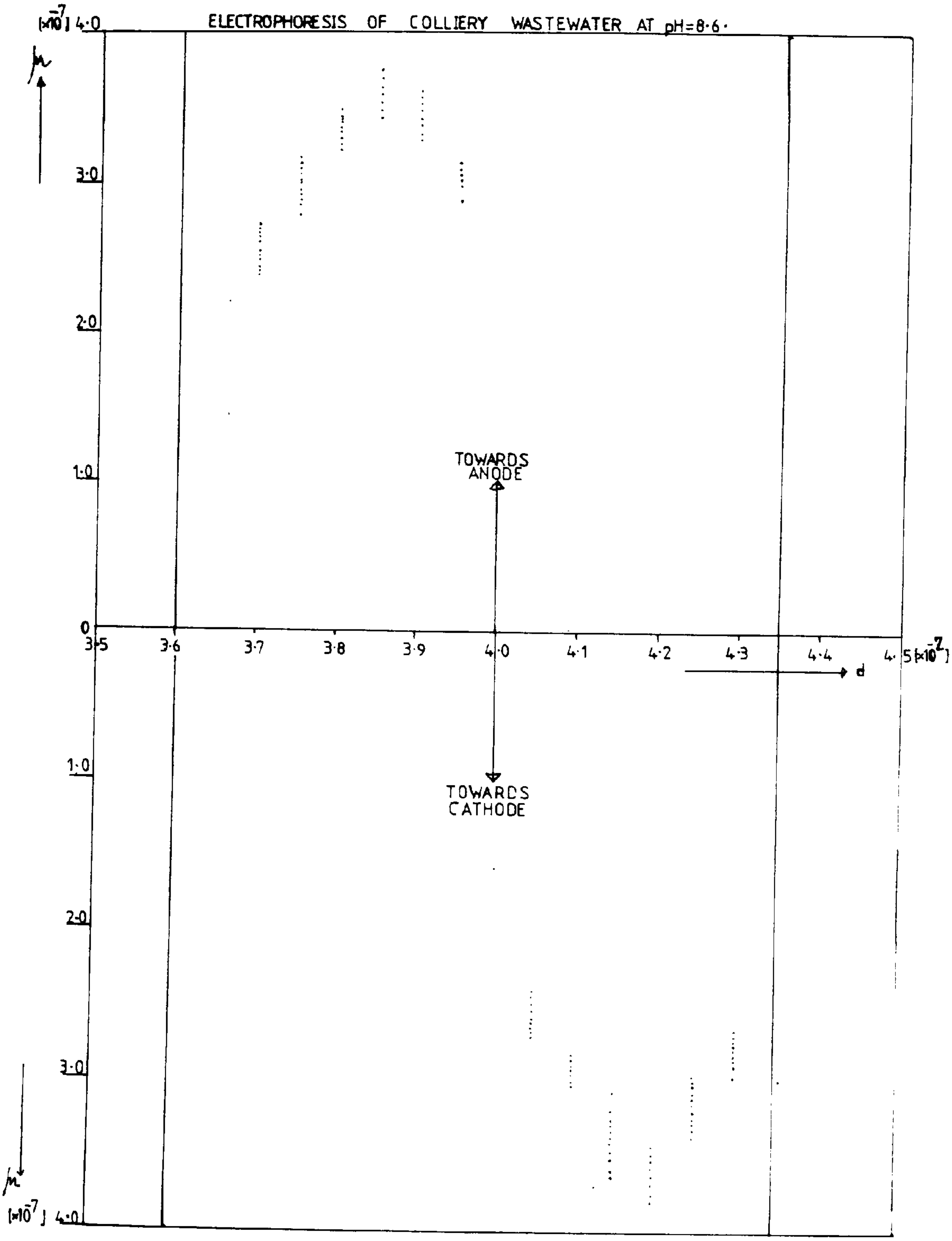

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=8·6·
(×10⁻⁷) 4·0
μ
3·0
2·0
1·0
0
1·0
2·0
3·0
μ
(×10⁻⁷) 4·0
3·5
3·6
3·7
3·8
3·9
4·0
4·1
4·2
4·3
4·4
4·5 (×10⁻²)
d
TOWARDS ANODE
TOWARDS CATHODE

FIGURE. 7.15

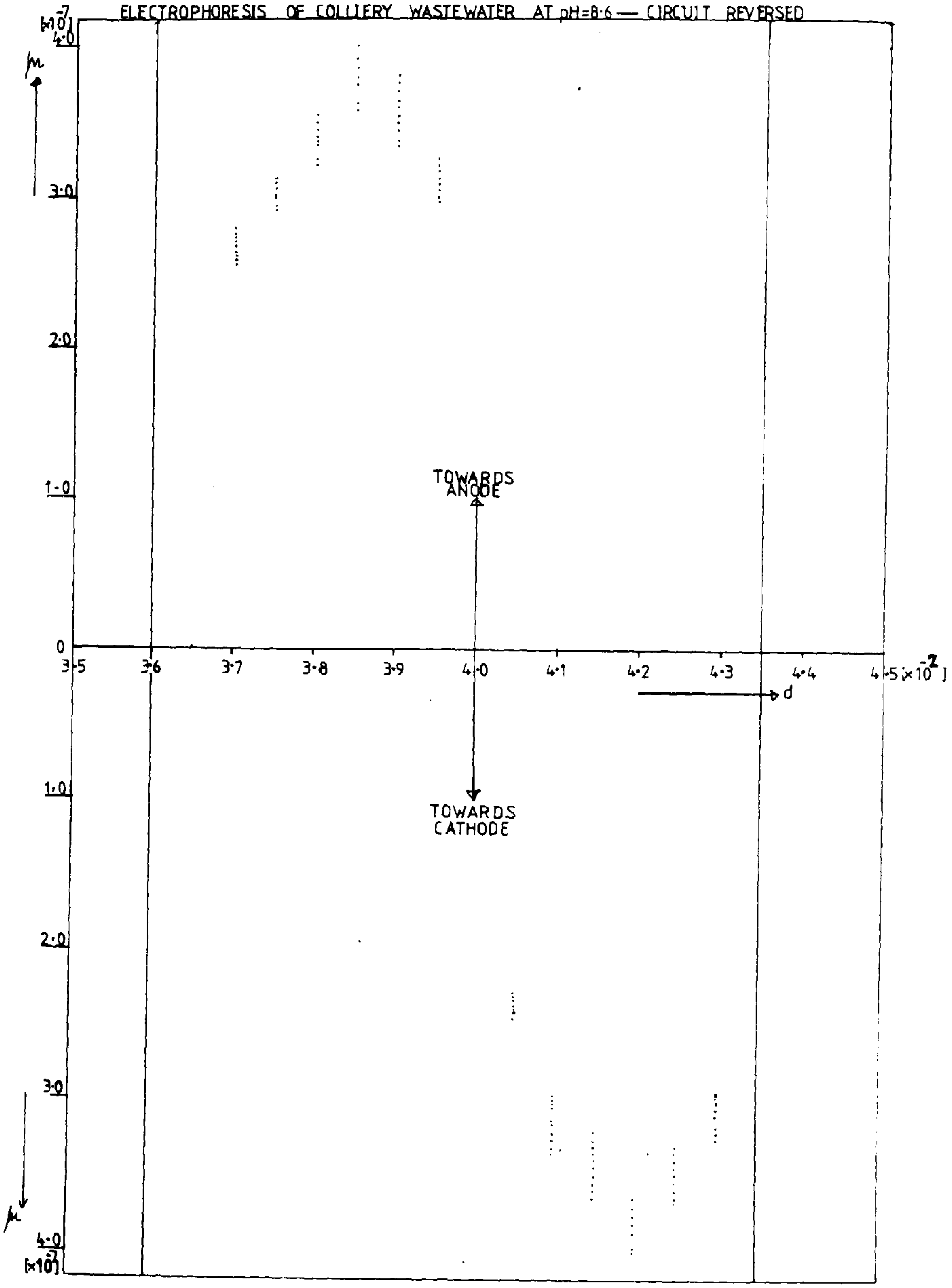
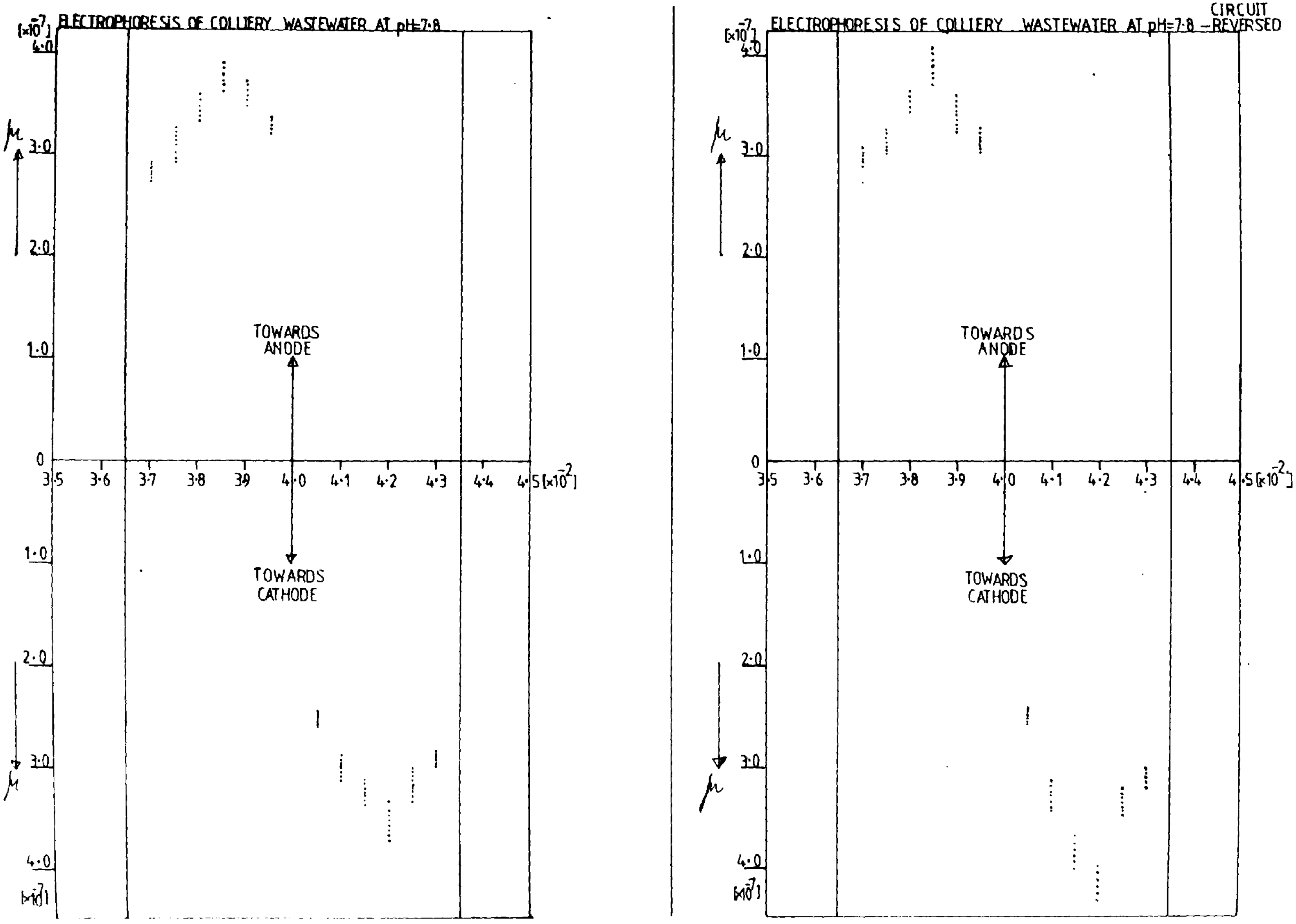

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=8·6 — CIRCUIT REVERSED
[×10^{-7}]
4·0
3·0
2·0
1·0
0
μ
TOWARDS ANODE
TOWARDS CATHODE
3·5
3·6
3·7
3·8
3·9
4·0
4·1
4·2
4·3
4·4
4·5 [×10^{-2}]
d

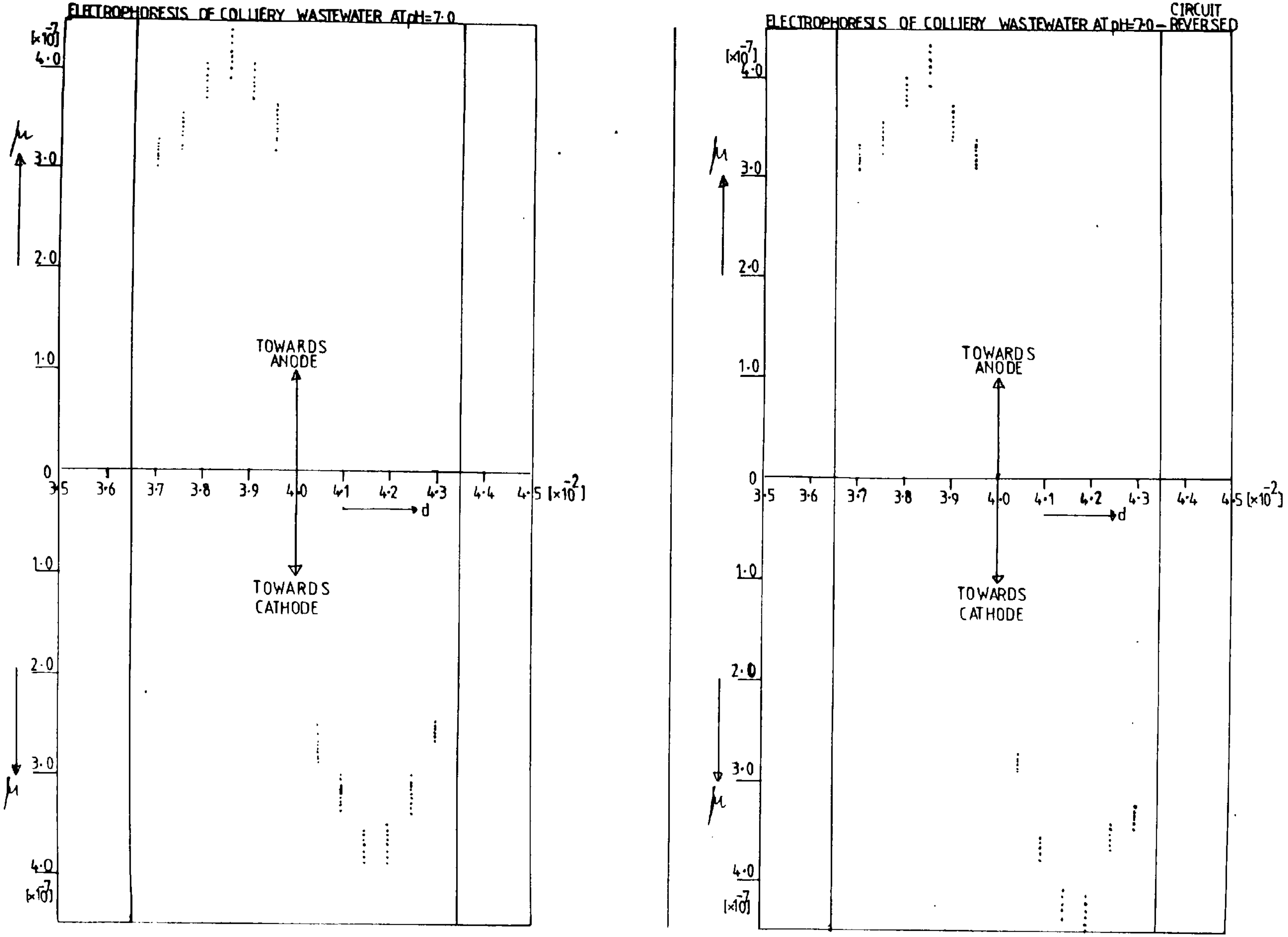
FIGURE. 7. 16



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·8

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·8 –REVERSED CIRCUIT

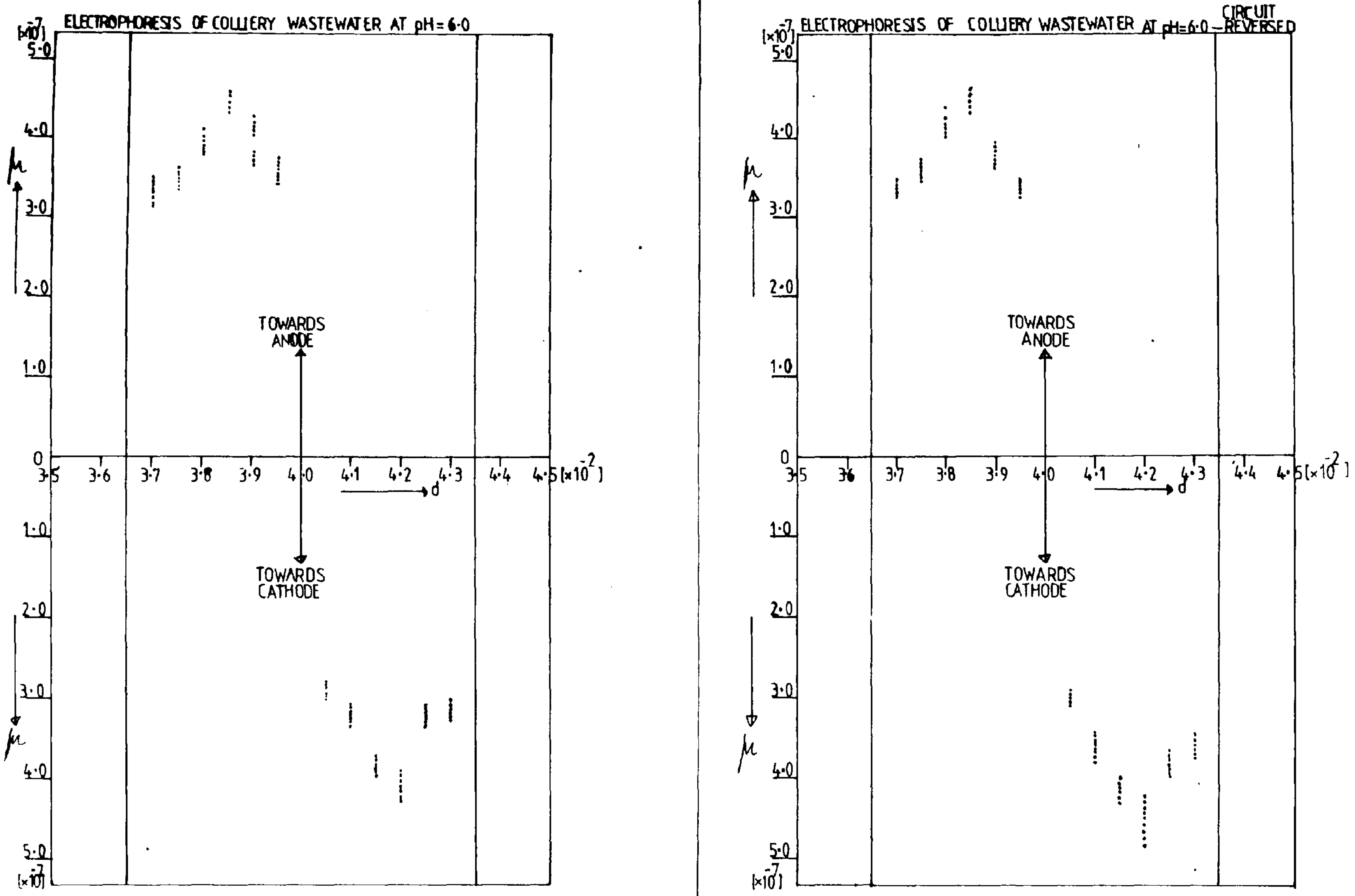
FIGURE. 7 17.



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·0

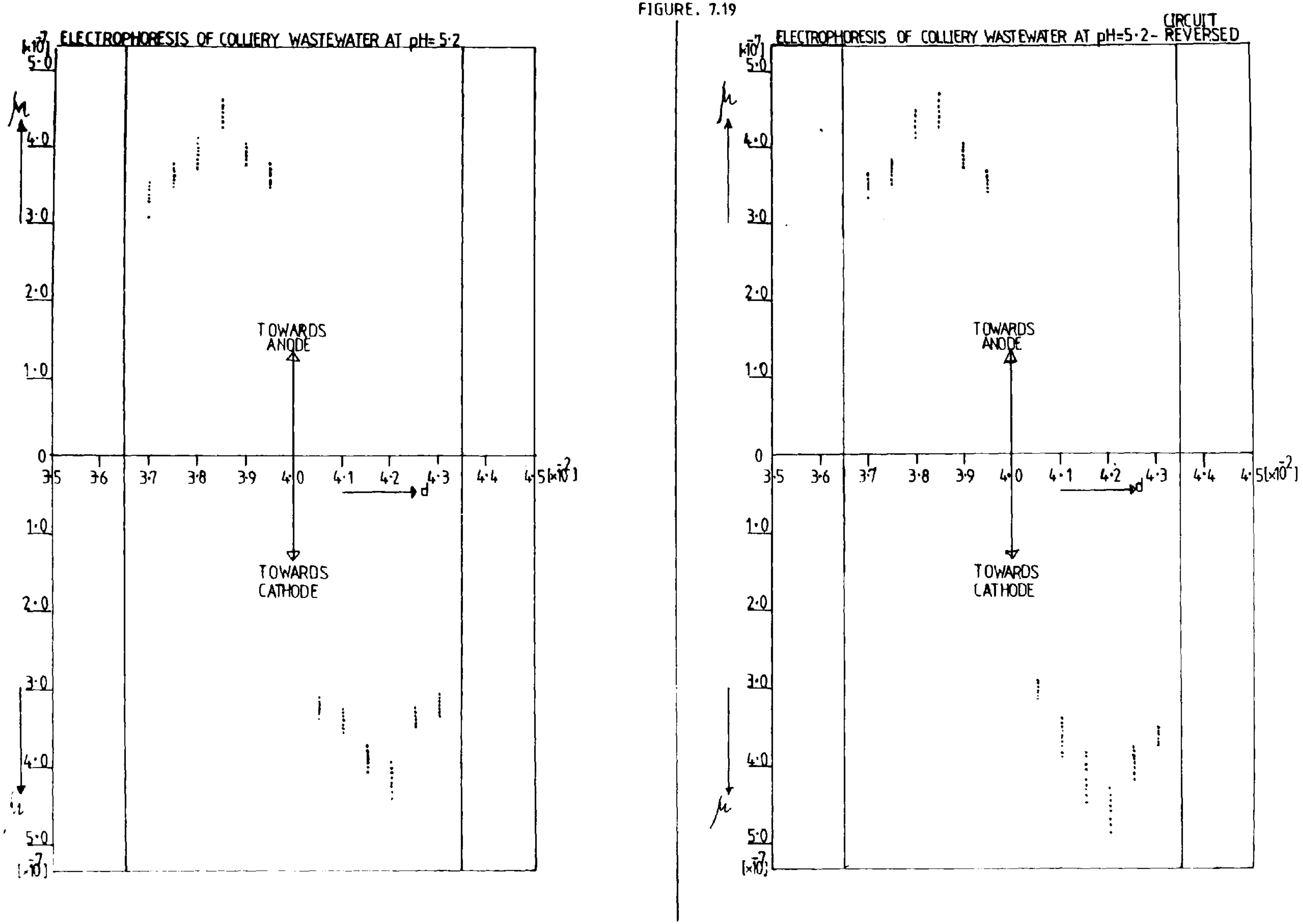
ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·0 — CIRCUIT REVERSED

FIGURE.7.18


ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=6·0

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=6·0 – CIRCUIT REVERSED

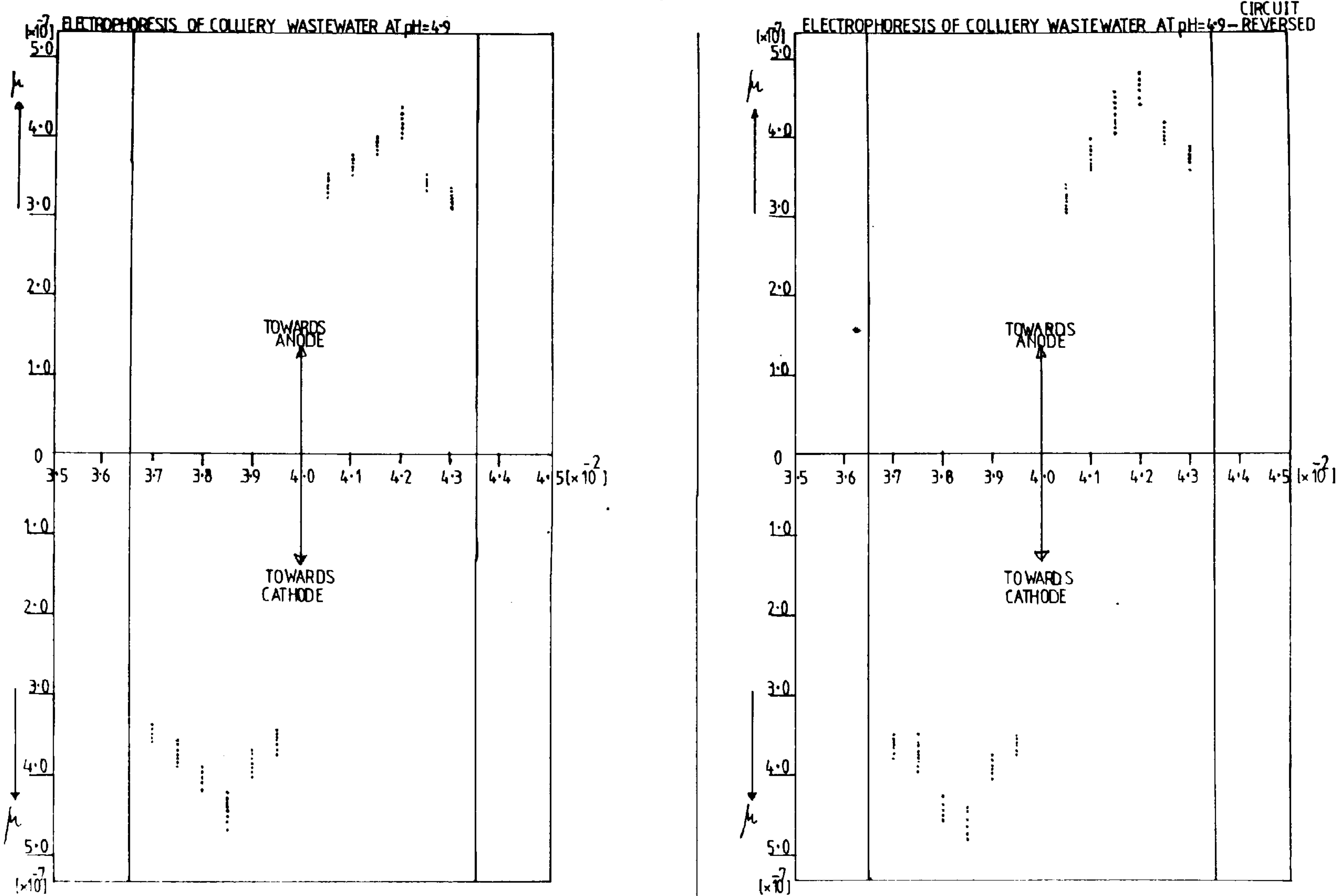
FIGURE. 7.19



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 5·2

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=5·2- CIRCUIT REVERSED

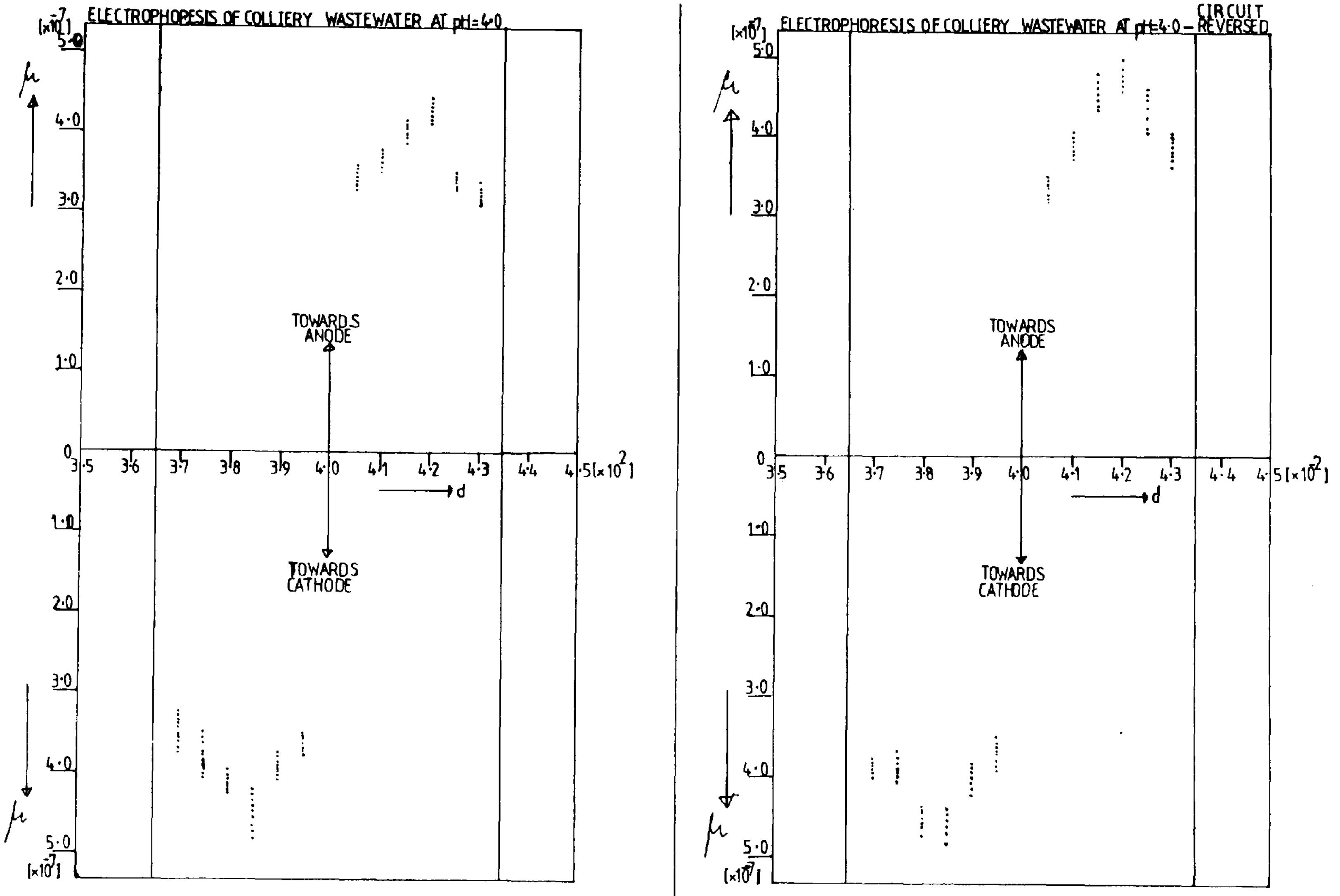
FIGURE. 7.20



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·9

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·9 – CIRCUIT REVERSED

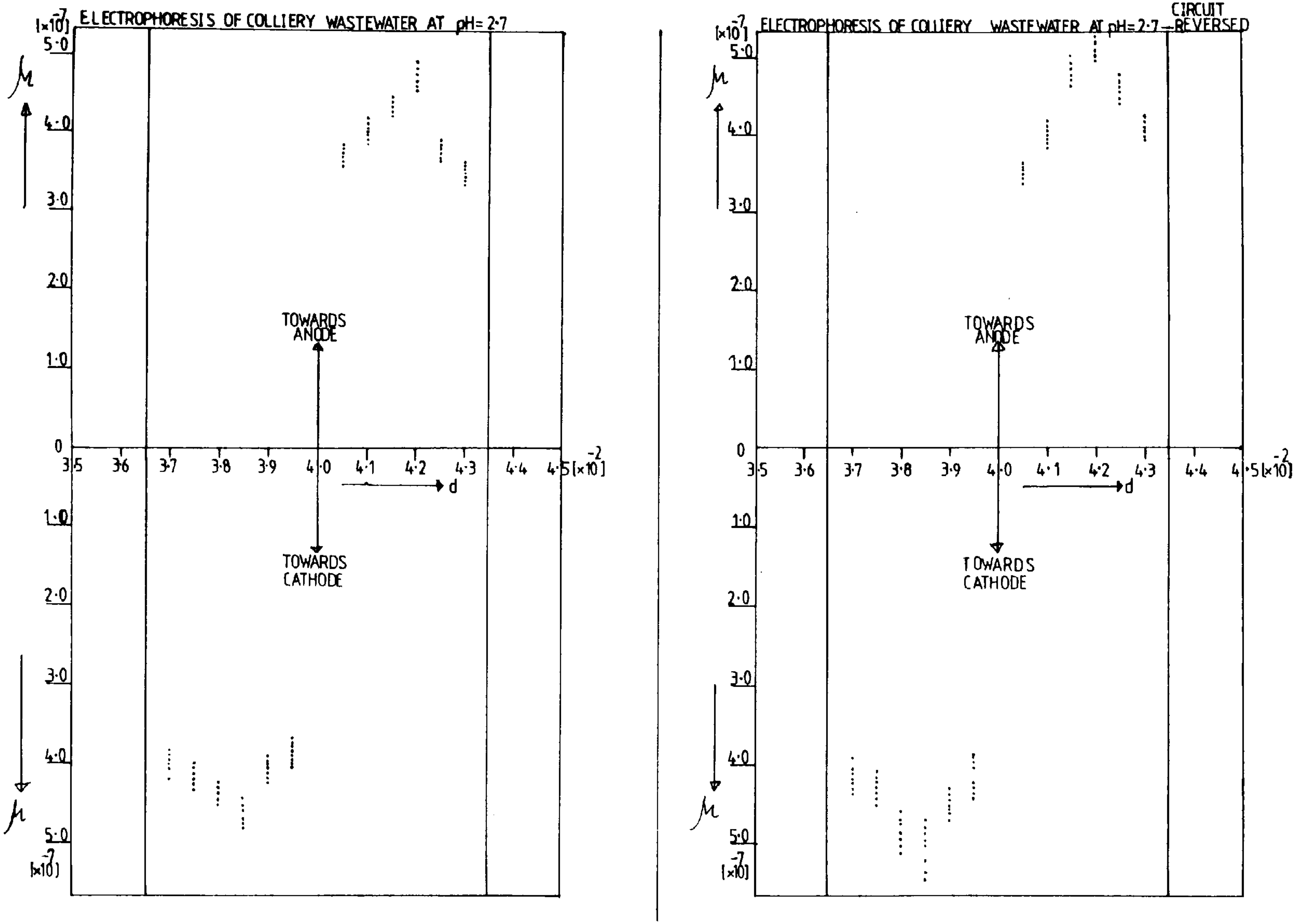
FIGURE. 7.21



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·0

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·0 – CIRCUIT REVERSED

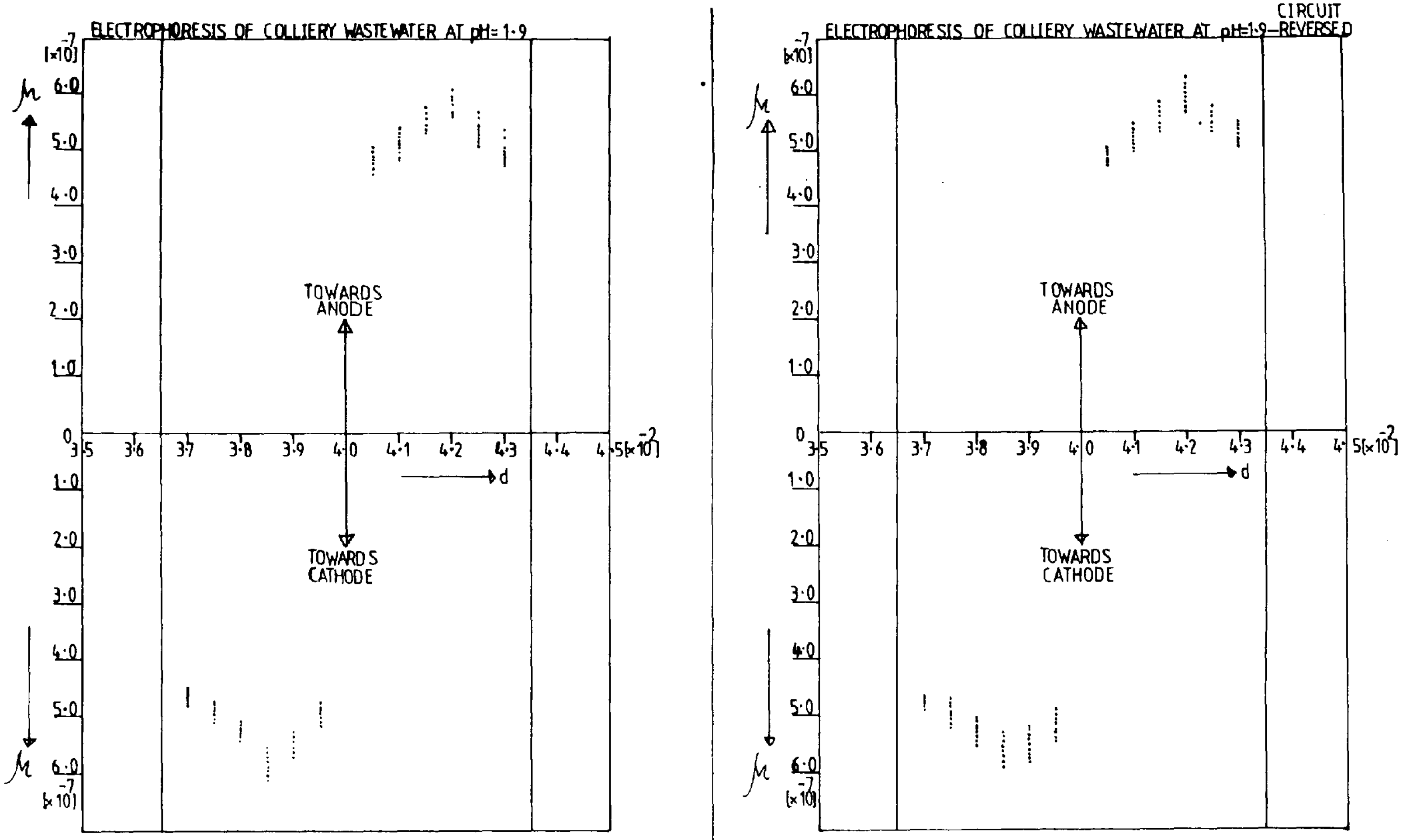
FIGURE. 7. 22



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 2·7

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 2·7 —CIRCUIT REVERSED

FIGURE. 7.23



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 1·9

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=1·9–REVERSED CIRCUIT

7.4 VARIATION OF pH WITH MOBILITY AND ZETA POTENTIAL - (HCl)

The graphs of mobility and zeta potential profiles at the same depth but against the different pH values have been illustrated in Figures 7.24 to 7.47 using hydrochloric acid.

For pH values between 8.60 and 5.20 and between the cell depth of 3.75 to 3.95 10^{-2}m., the particles moved towards the anode and between the cell depth of 4.05 to 4.30 10^{-2}(m), the particles moved towards the cathode.

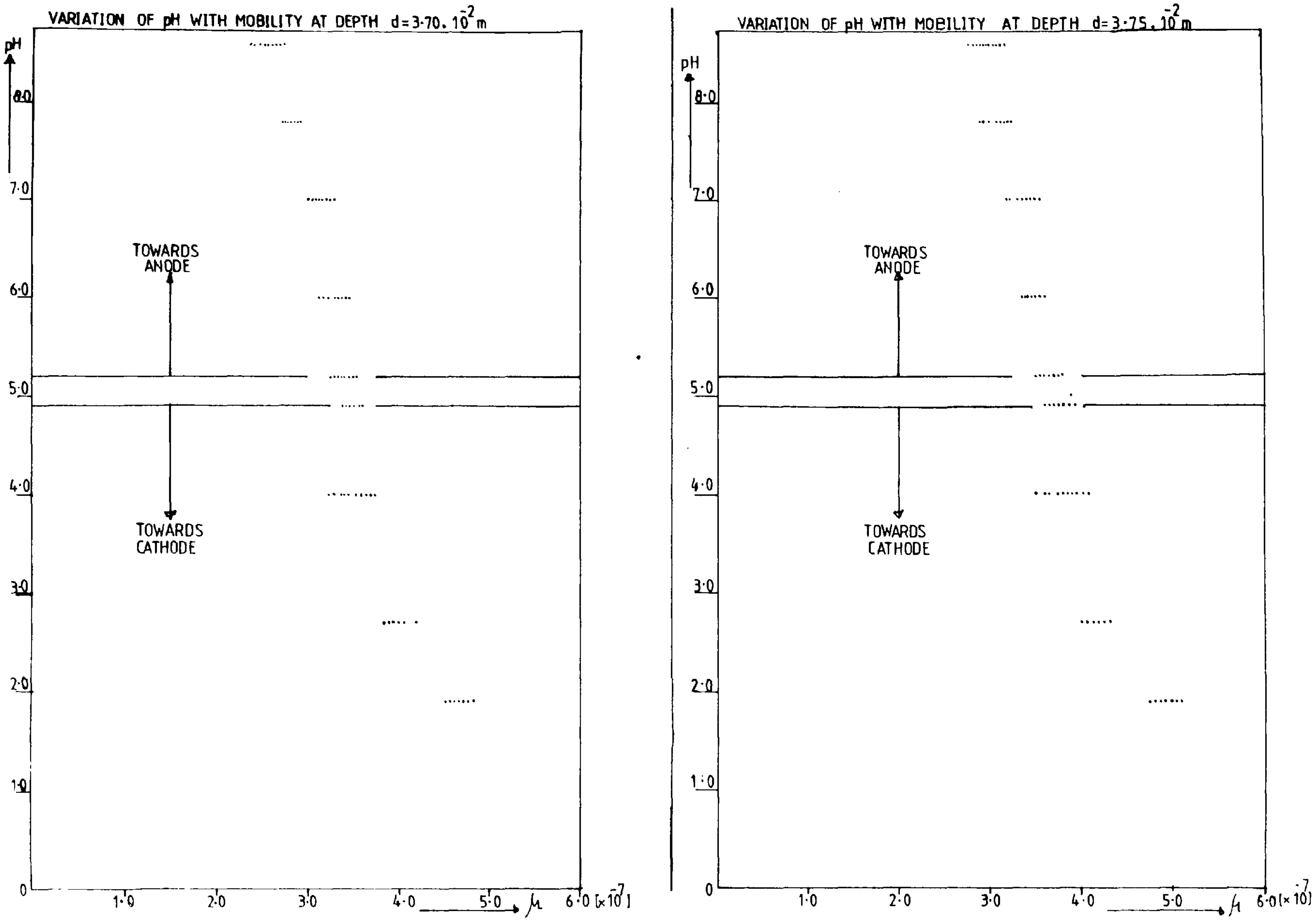
Between the pH values of 5.20 and 4.90, some particles moved towards the anode, some towards the cathode, and some in random motion and some virtually at rest (not moving in any direction). Since the movement of the particles was towards both the anode and cathode, there could be the same number of positive and negative charges and hence this could be the iso-electric point (IEP) (4,10,14,148,149).

At pH values of 4.9 or less and between the cell depth of 3.70 to 3.95 10^{-2}m, the particles moved towards the cathode (charge reversal) and between the cell depth of 4.05 to 4.30 10^{-2}m, the particles moved towards the anode (charge reversal), hence this pH value of 4.9 is known as the zero point of charge (zpc) which is defined as the pH at which the electrophoretic mobility of fines is zero(4,10,148,149). The existence of the zero point of charge thus explains the reversal of charge.

From these graphs the iso-electric point and the zero point of charge should coincide. It has been suggested by

Parks(13), Mular et al(148) and Hunter(4) that the observed zero point of charge should coincide with the iso-electric point of the solution.

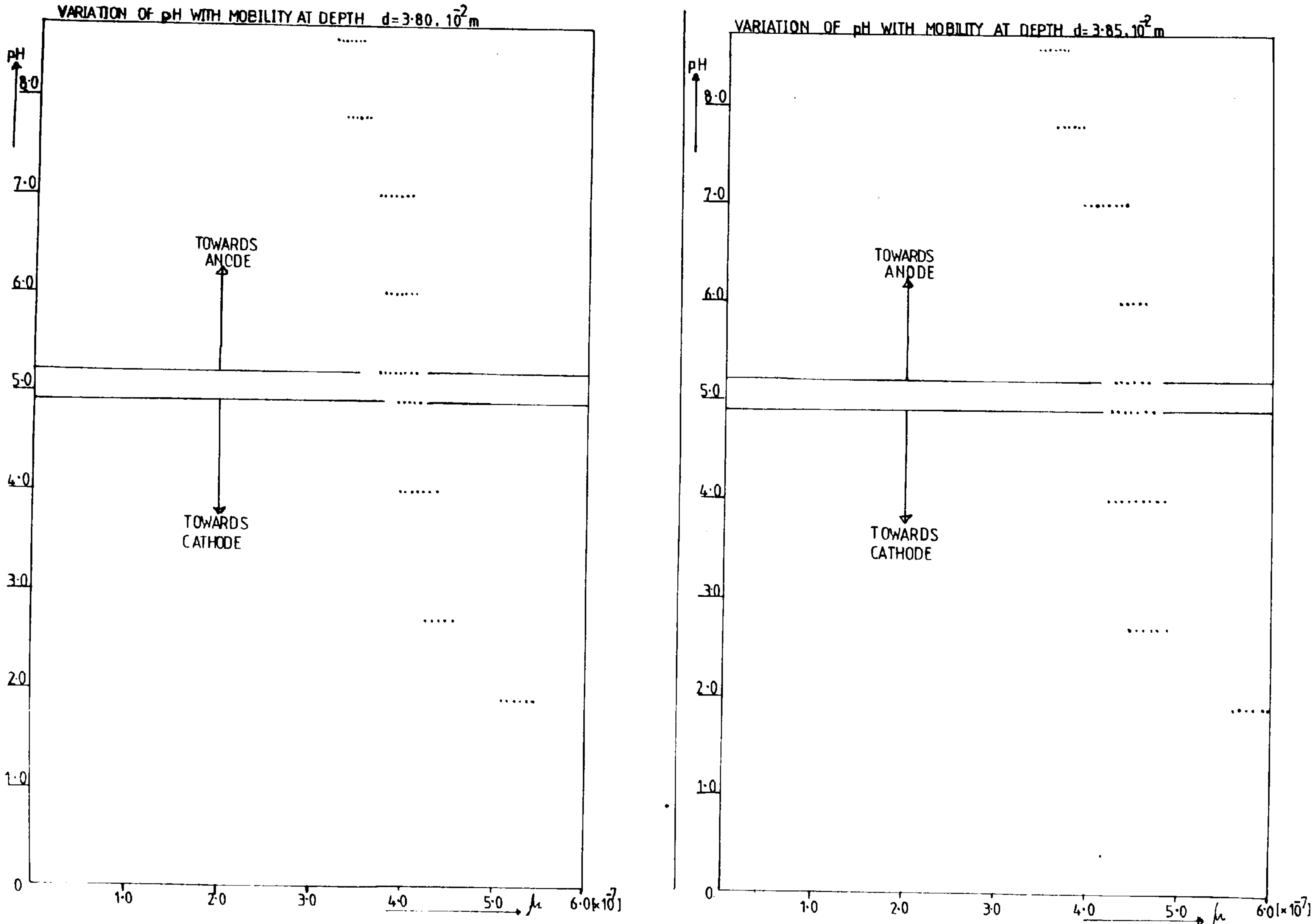
FIGURE. 7.24



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}70 . 10^{-2}$ m

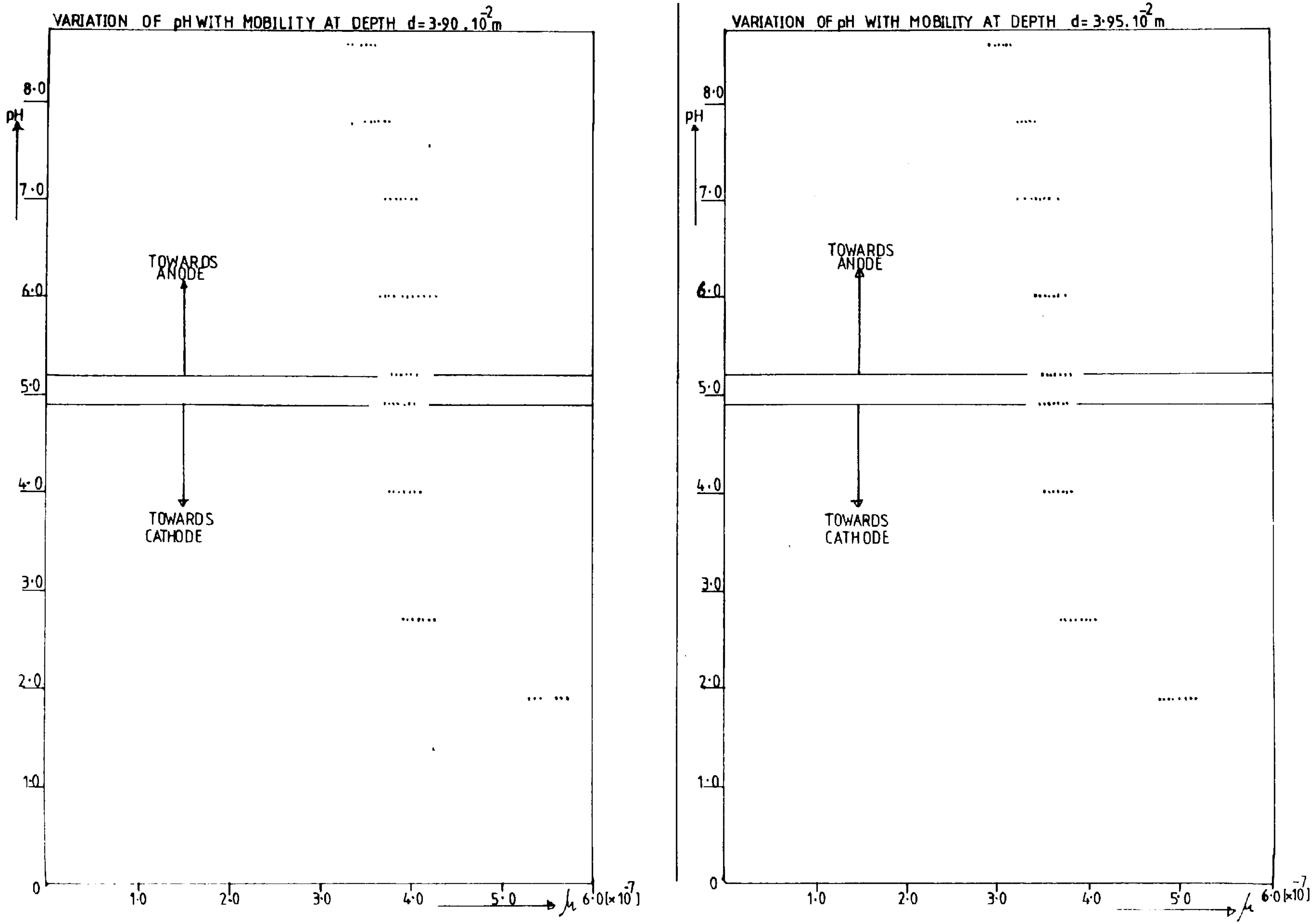
VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}75 . 10^{-2}$ m

FIGURE. 7. 25


VARIATION OF pH WITH MOBILITY AT DEPTH d=3·80. 10^{-2}m

VARIATION OF pH WITH MOBILITY AT DEPTH d=3·85. 10^{-2}m

FIGURE. 7. 26



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}90 . 10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}95 . 10^{-2}$ m

FIGURE. 7.27

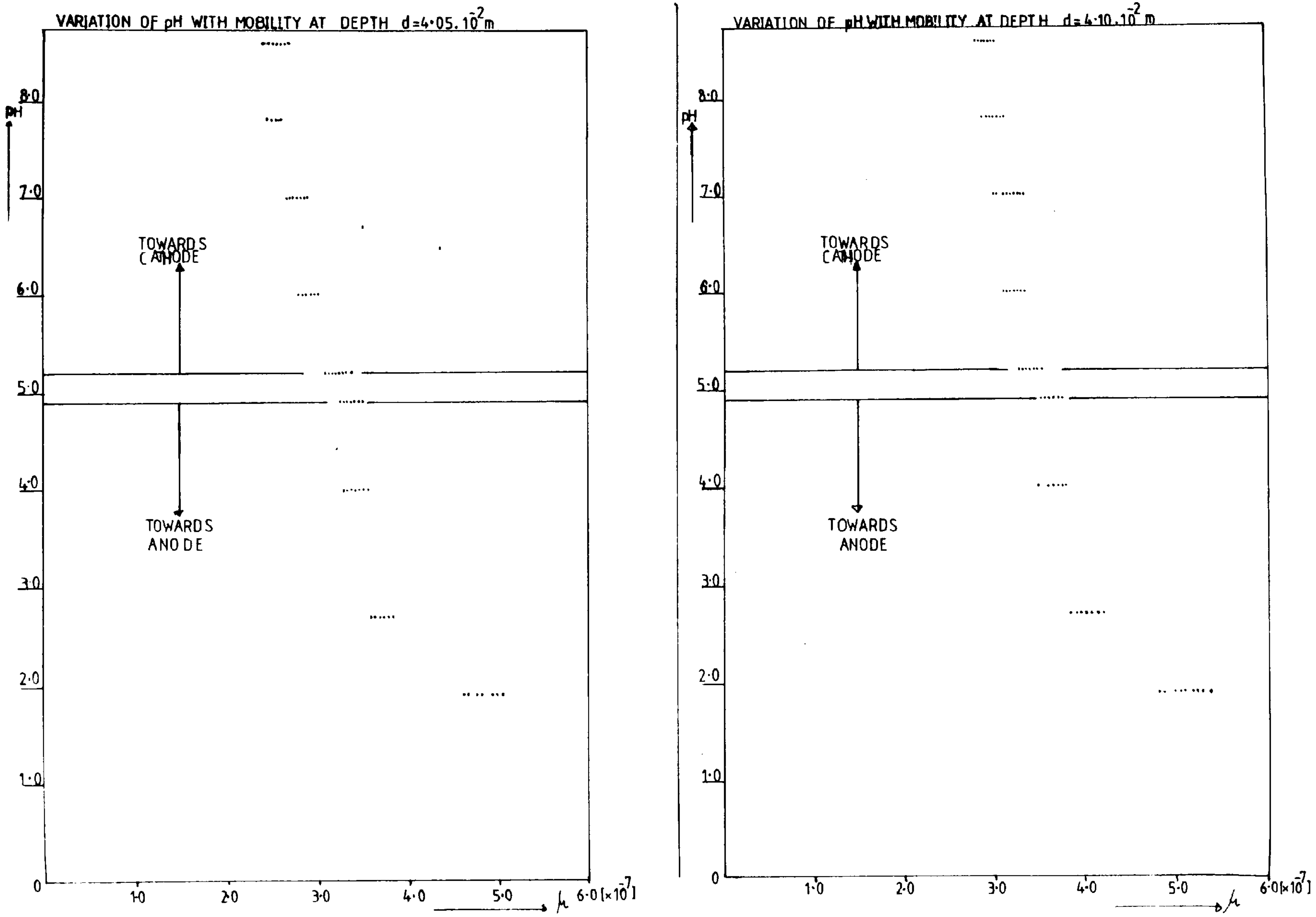
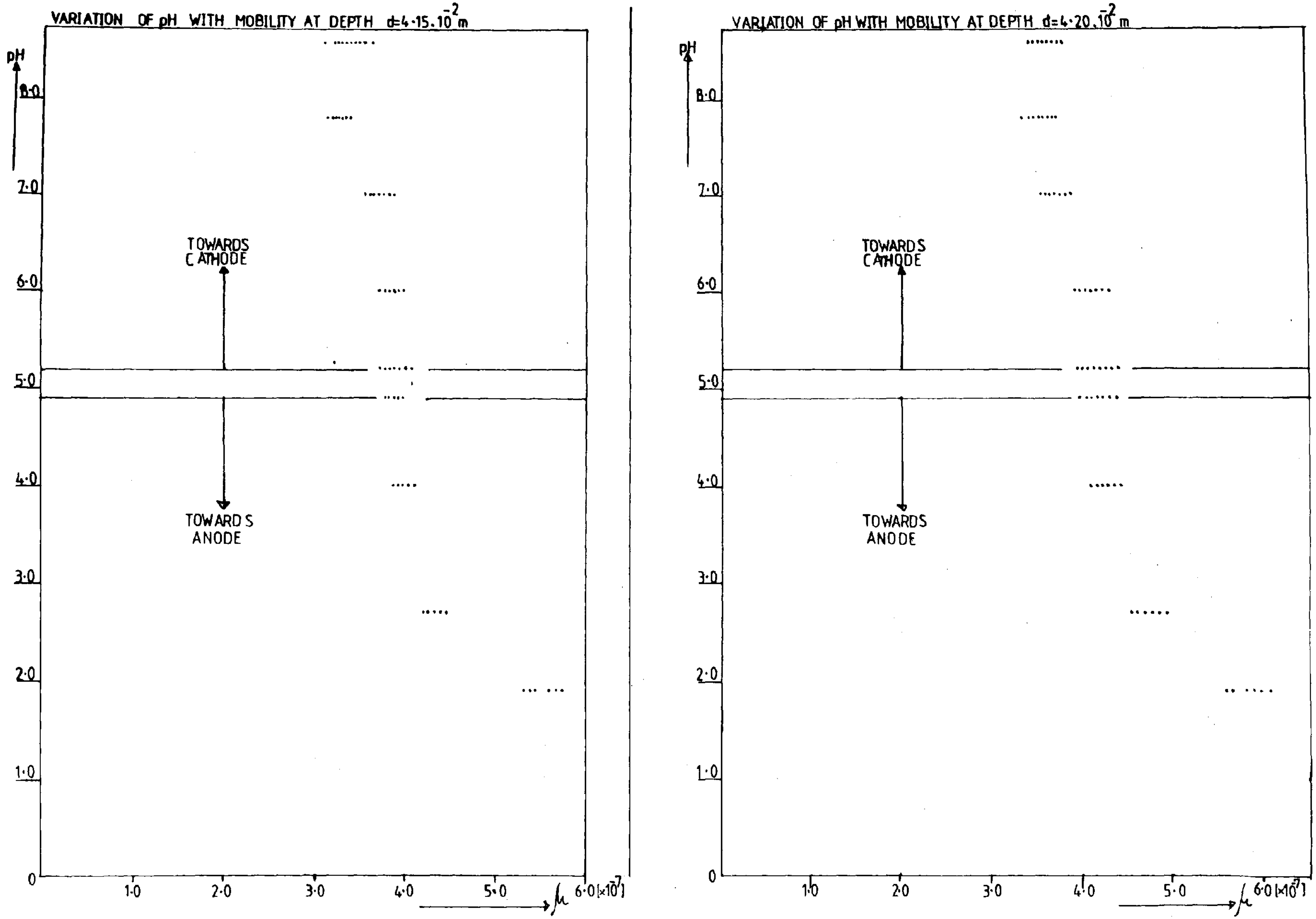

VARIATION OF pH WITH MOBILITY AT DEPTH d=4·05.10⁻²m
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS CATHODE
TOWARDS ANODE
1·0
2·0
3·0
4·0
5·0
6·0 [×10⁻⁷]
μ
VARIATION OF pH WITH MOBILITY AT DEPTH d=4·10.10⁻²m
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS CATHODE
TOWARDS ANODE
1·0
2·0
3·0
4·0
5·0
6·0 [×10⁻⁷]
μ

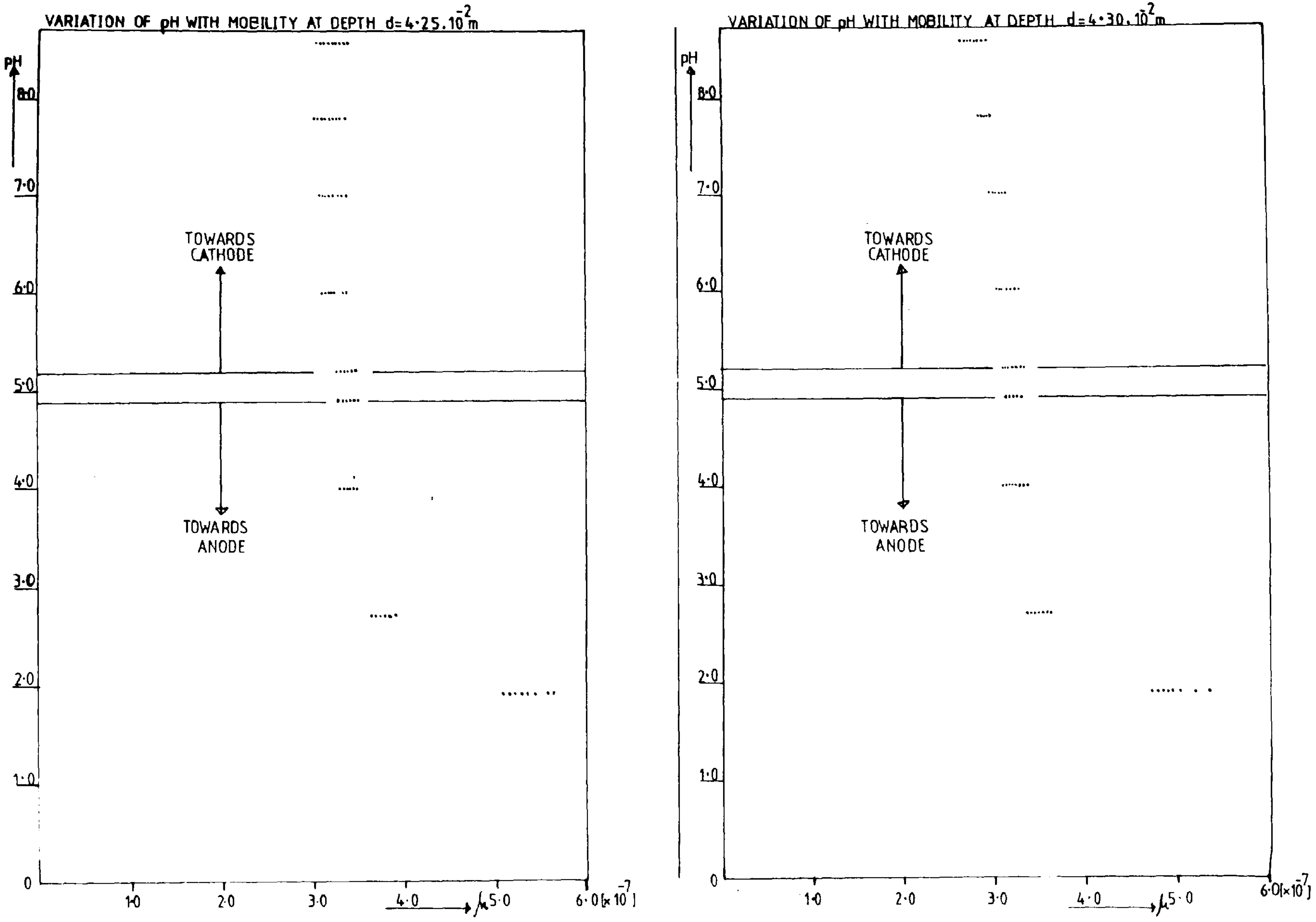
FIGURE. 7.28



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}15.10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}20.10^{-2}$ m

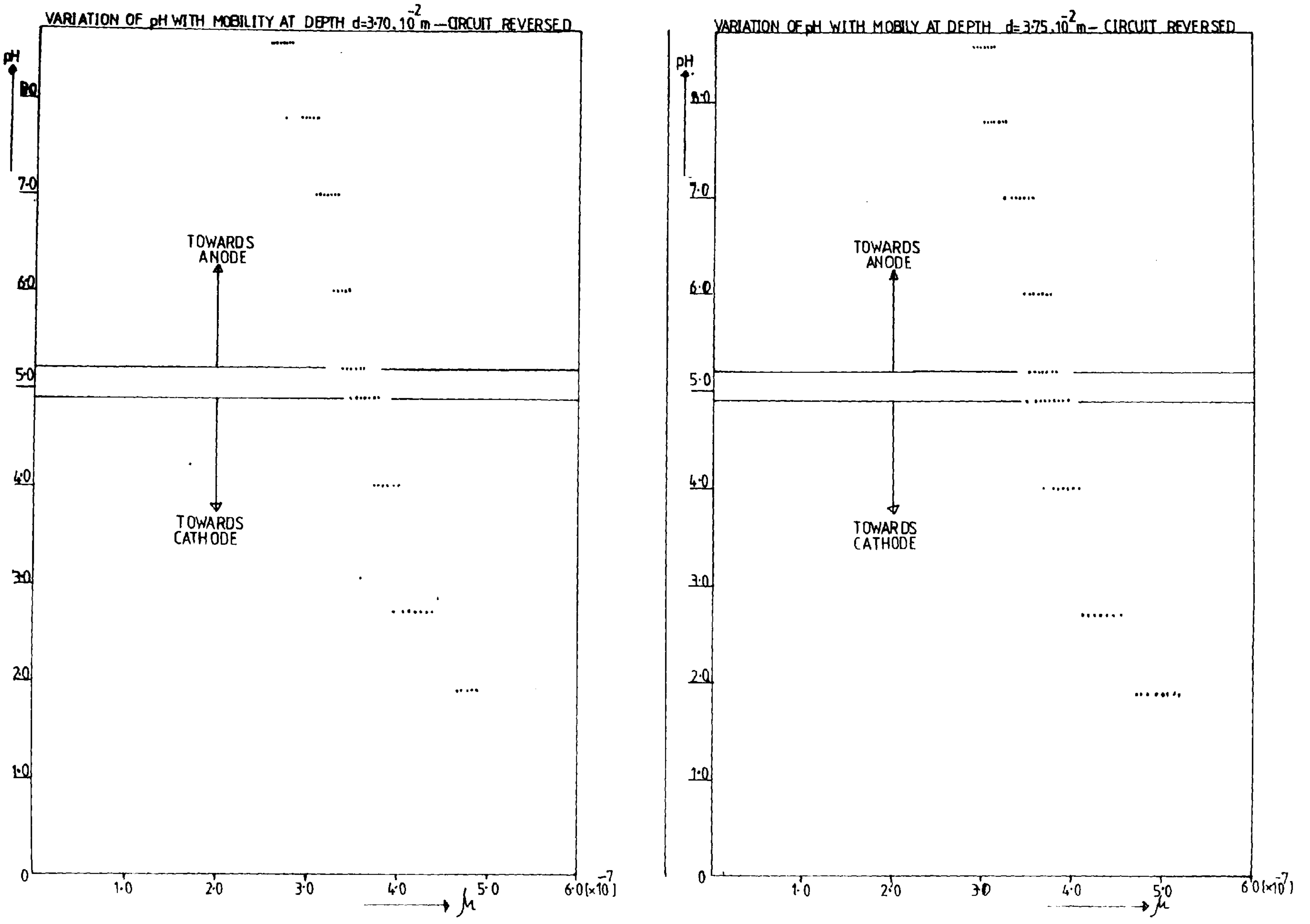
FIGURE. 7. 29



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}25.10^{-2}$m

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}30.10^{-2}$m

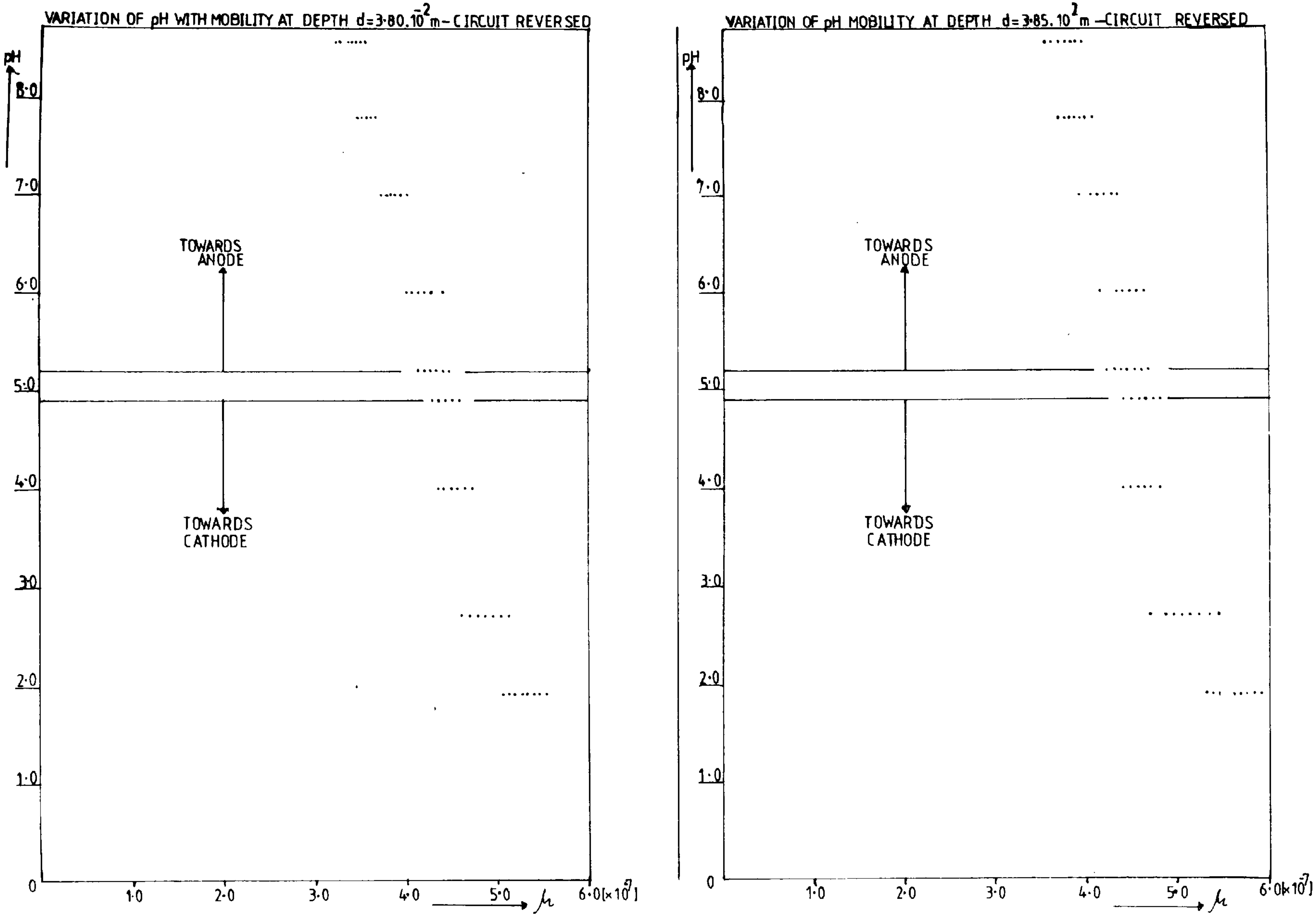
FIGURE. 7.30



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}70.10^{-2}\,m$ — CIRCUIT REVERSED

VARIATION OF pH WITH MOBILY AT DEPTH $d = 3{\cdot}75.10^{-2}\,m$ – CIRCUIT REVERSED

FIGURE. 7. 31



VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}80.10^{-2}$ m – CIRCUIT REVERSED

VARIATION OF pH MOBILITY AT DEPTH $d=3{\cdot}85.10^{-2}$ m – CIRCUIT REVERSED

FIGURE. 7. 32

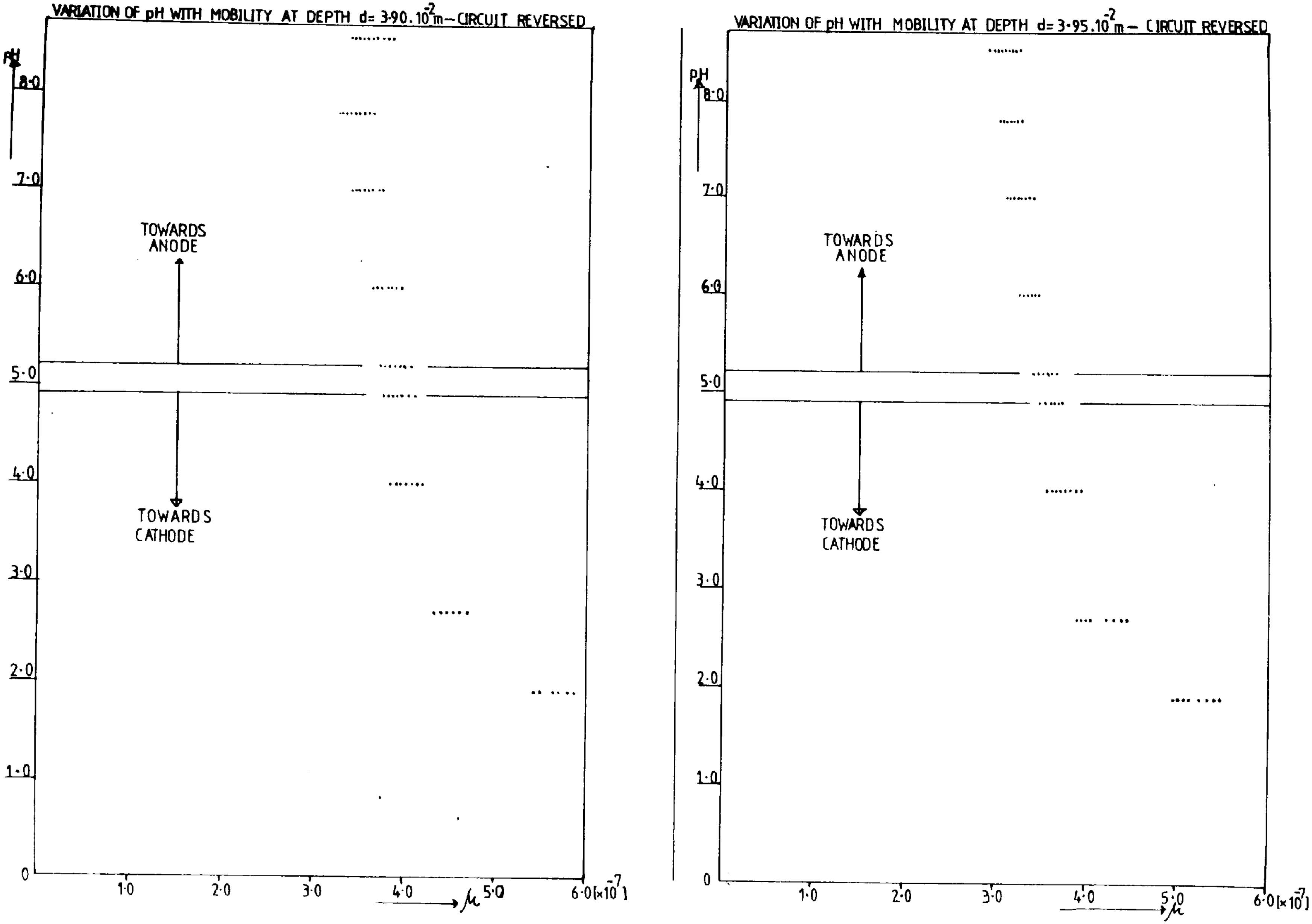
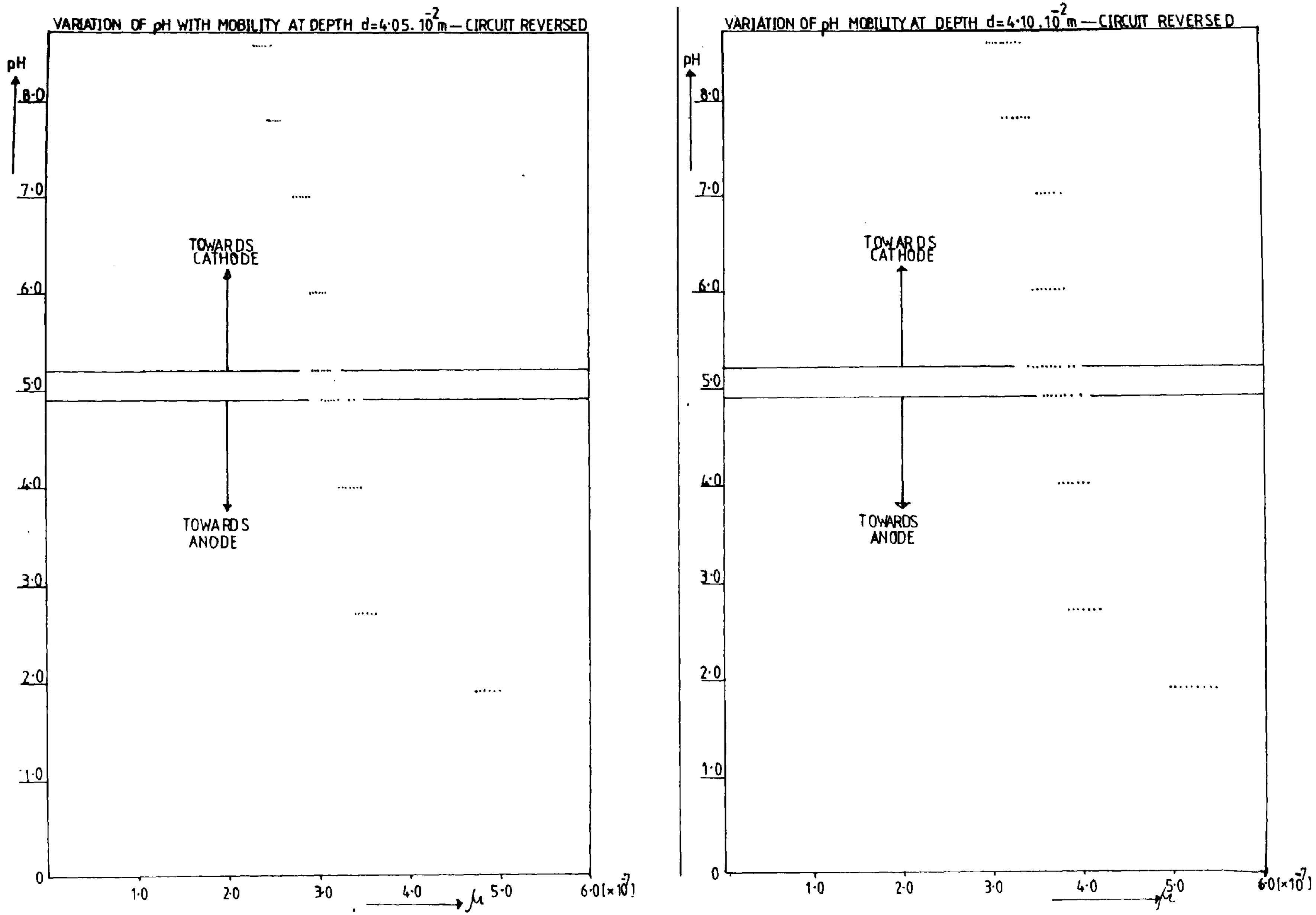

VARIATION OF pH WITH MOBILITY AT DEPTH d= 3·90.10⁻²m—CIRCUIT REVERSED
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS ANODE
TOWARDS CATHODE
1·0
2·0
3·0
4·0
μ
5·0
6·0(×10⁻⁷)
VARIATION OF pH WITH MOBILITY AT DEPTH d= 3·95.10⁻²m— CIRCUIT REVERSED
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS ANODE
TOWARDS CATHODE
1·0
2·0
3·0
4·0
5·0
μ
6·0(×10⁻⁷)

FIGURE. 7.33

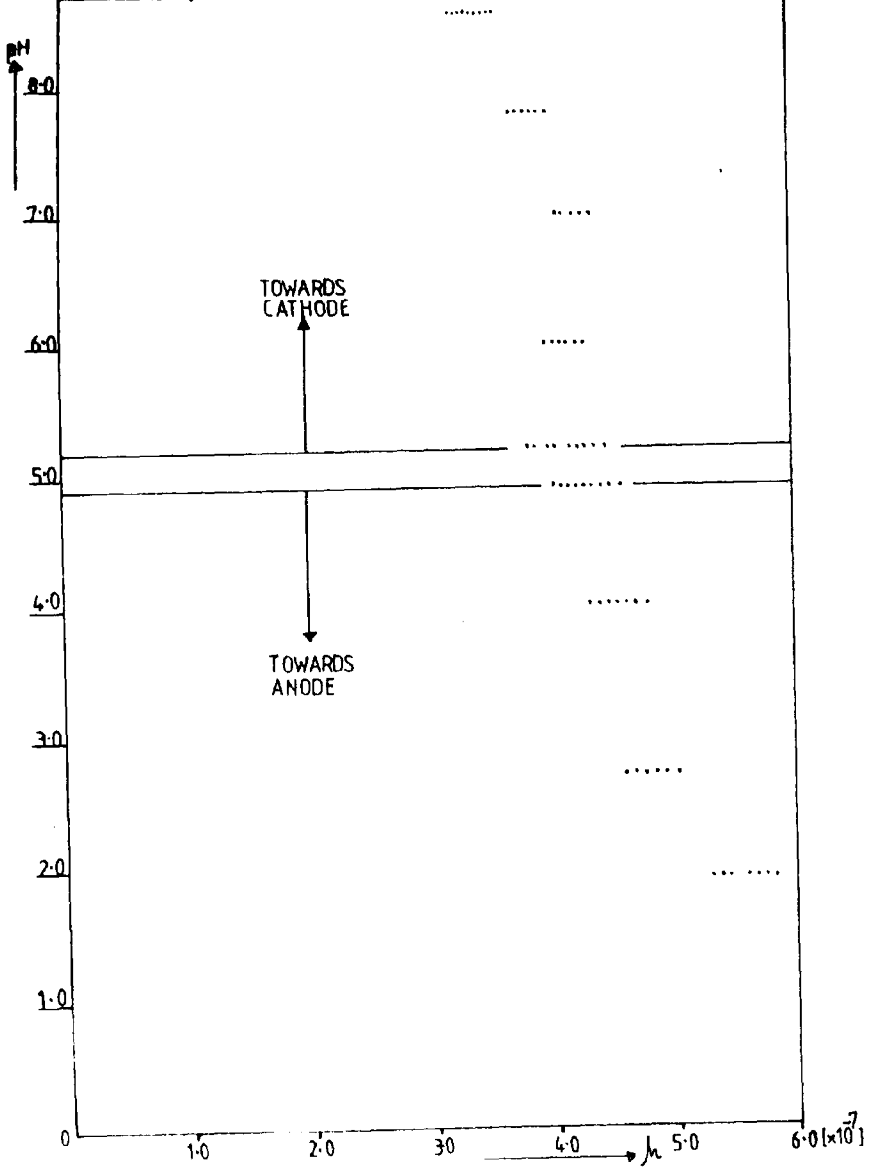


VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}05.10^{-2}m$ — CIRCUIT REVERSED

VARIATION OF pH MOBILITY AT DEPTH $d=4{\cdot}10.10^{-2}m$ — CIRCUIT REVERSED

FIGURE. 7.34

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}15.10^{-2}m$—CIRCUIT REVERSED



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}20.10^{-2}m$—CIRCUIT REVERSED

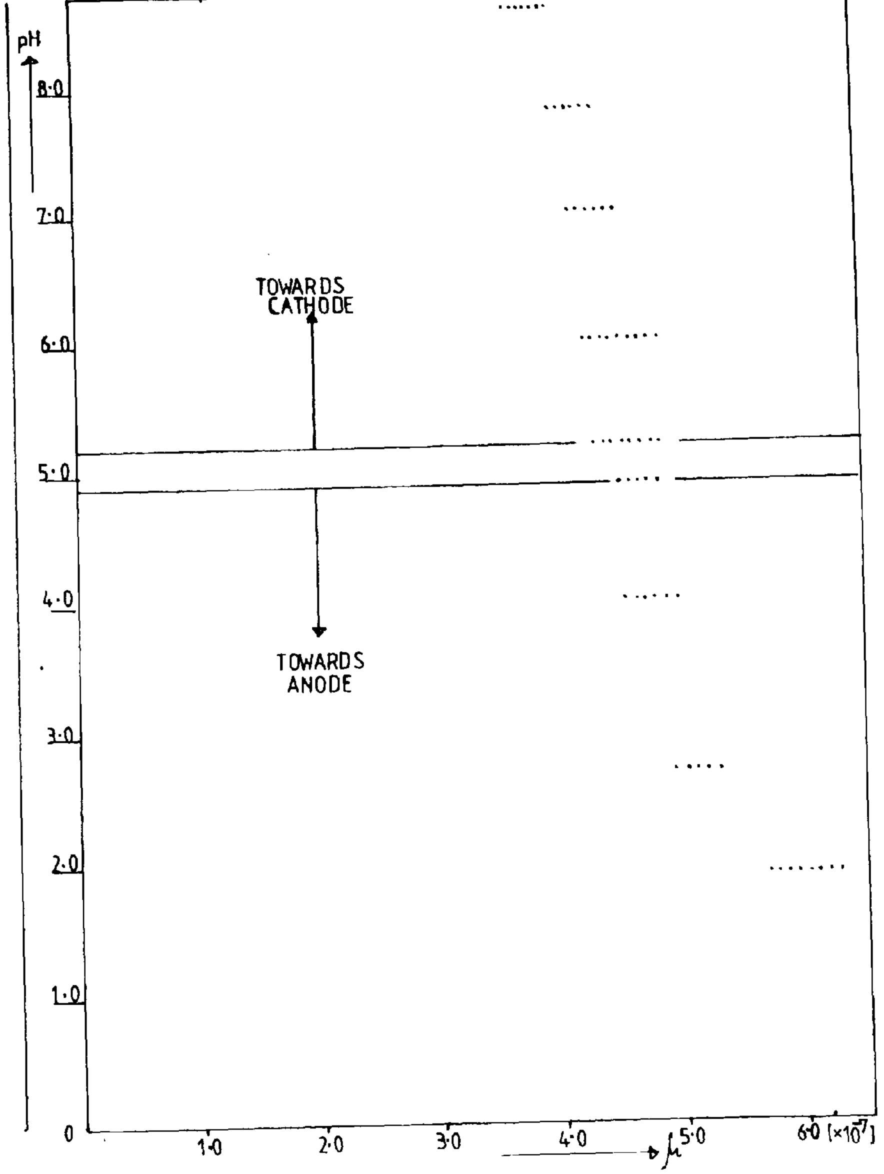
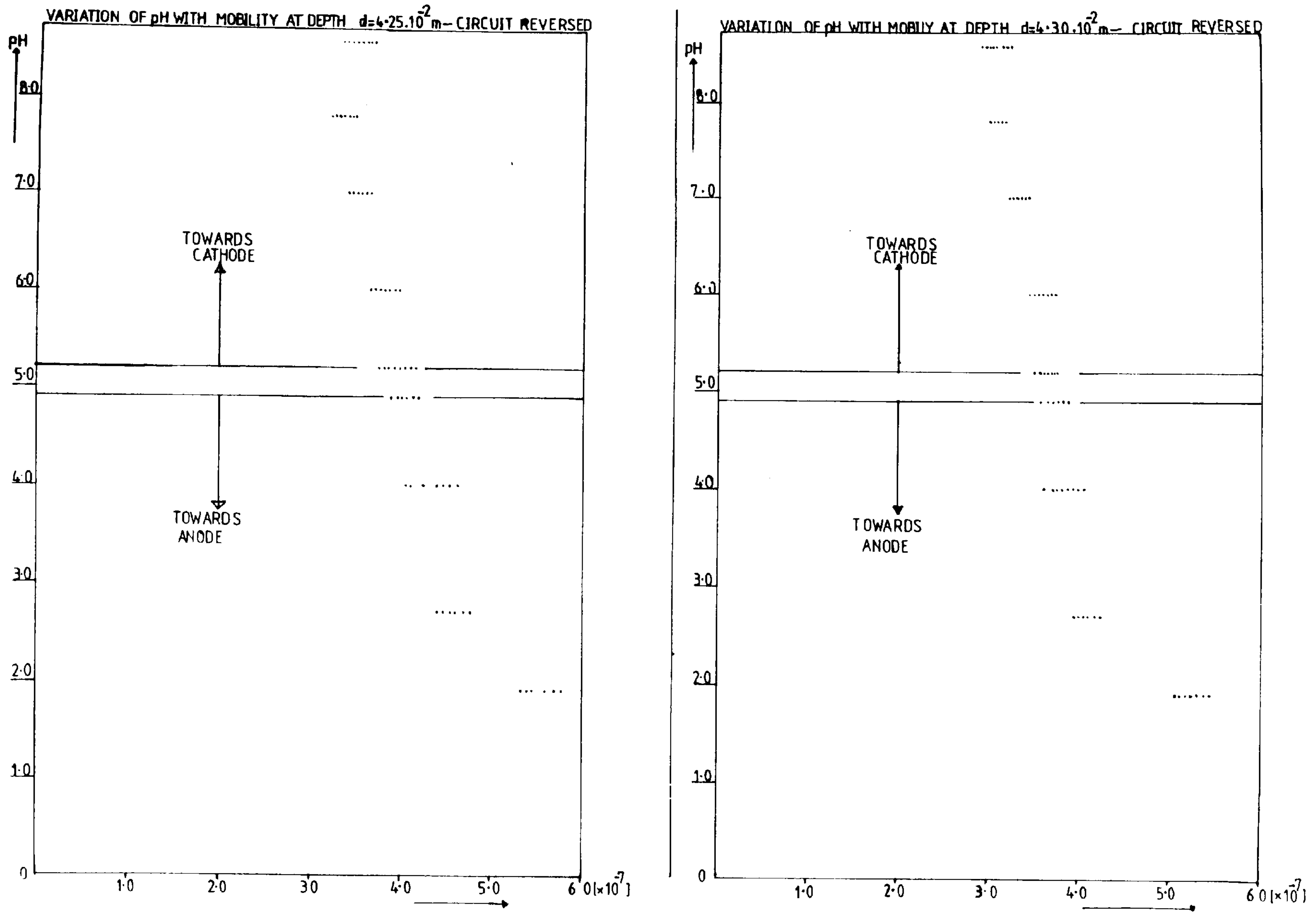


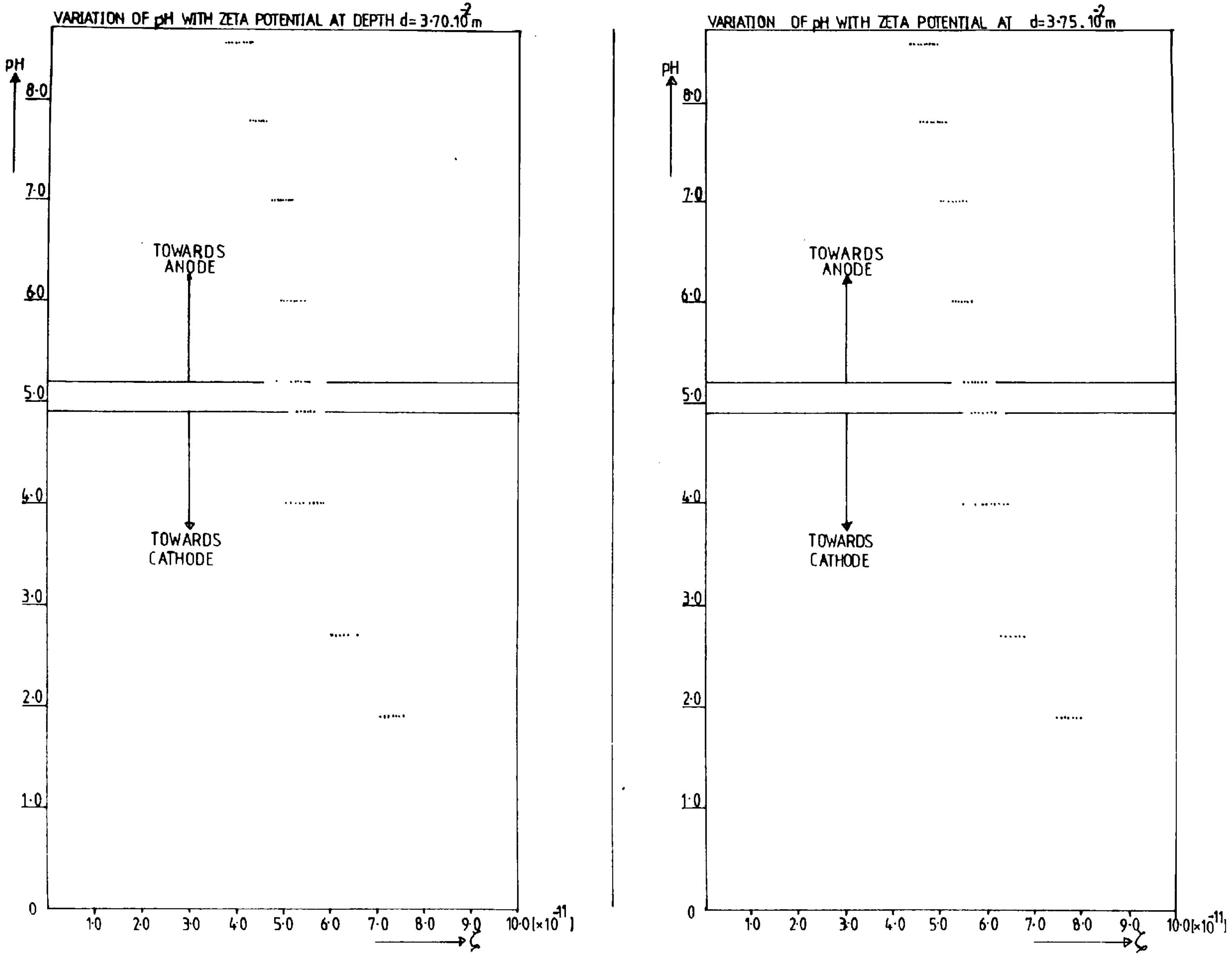
FIGURE.7.35



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}25.10^{-2}$m – CIRCUIT REVERSED

VARIATION OF pH WITH MOBIlY AT DEPTH $d=4{\cdot}30.10^{-2}$m – CIRCUIT REVERSED

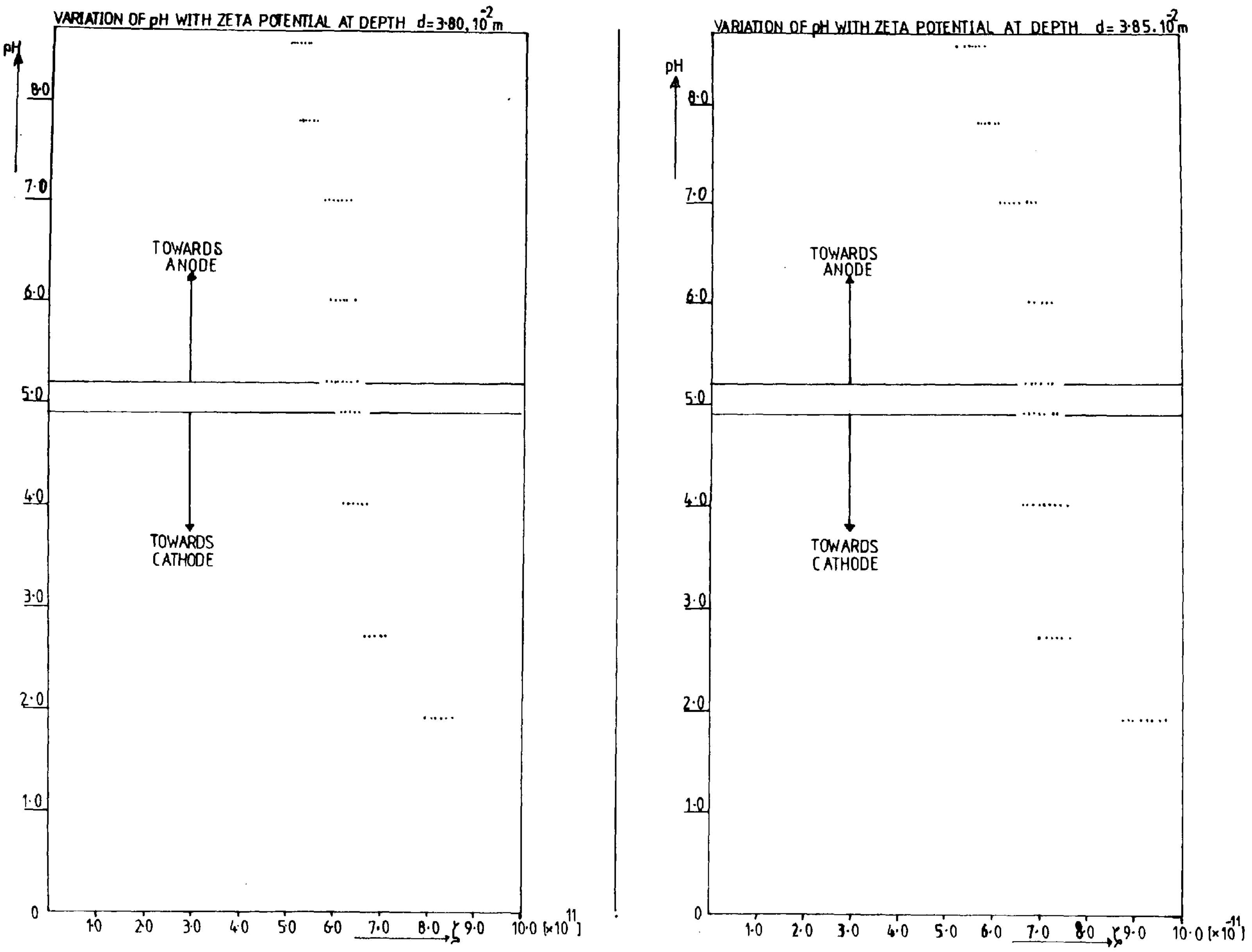
FIGURE. 7, 36



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d = 3{\cdot}70.10^{-2}$ m

VARIATION OF pH WITH ZETA POTENTIAL AT $d = 3{\cdot}75.10^{-2}$ m

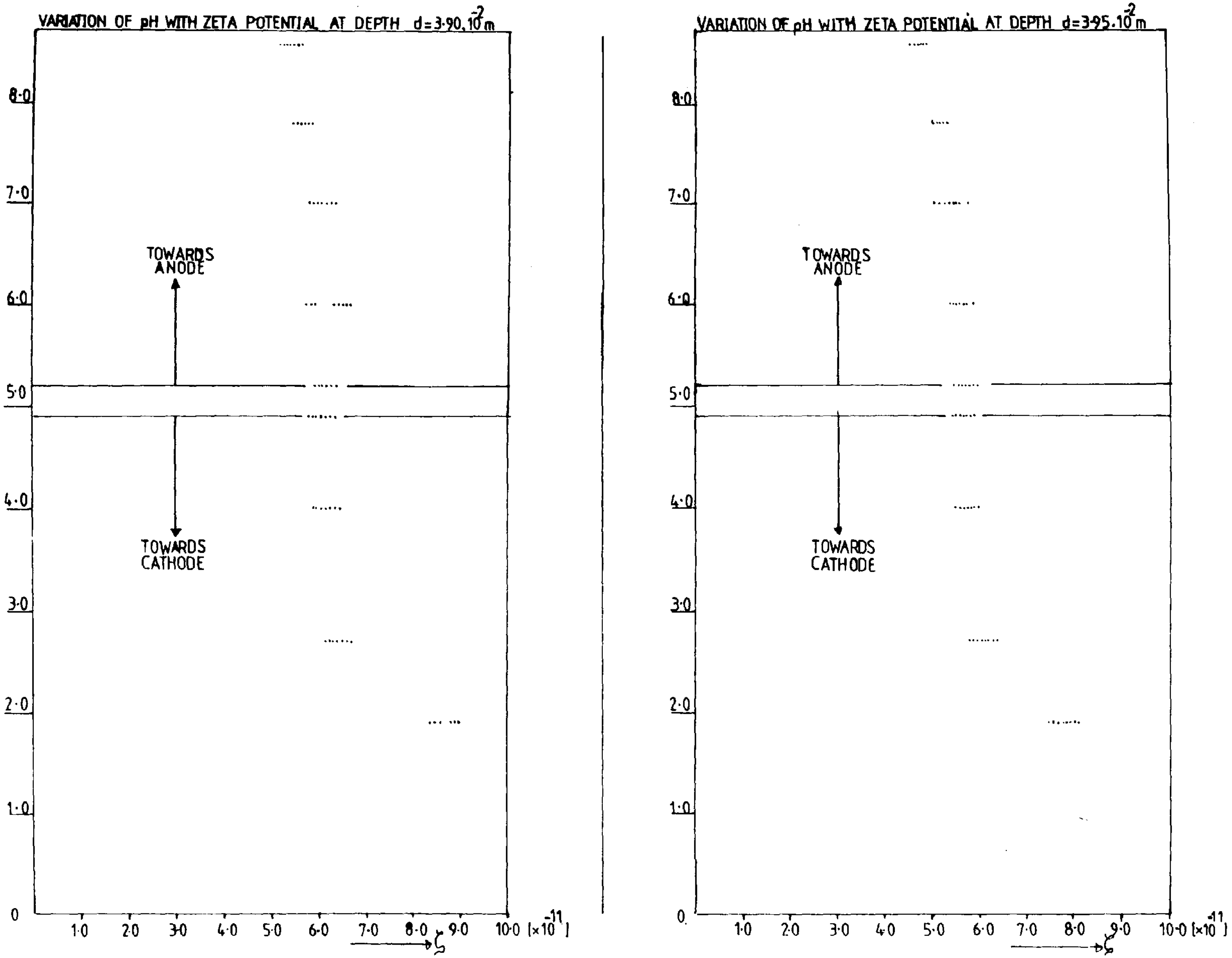
FIGURE.7.37



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}80.10^{-2}$ m

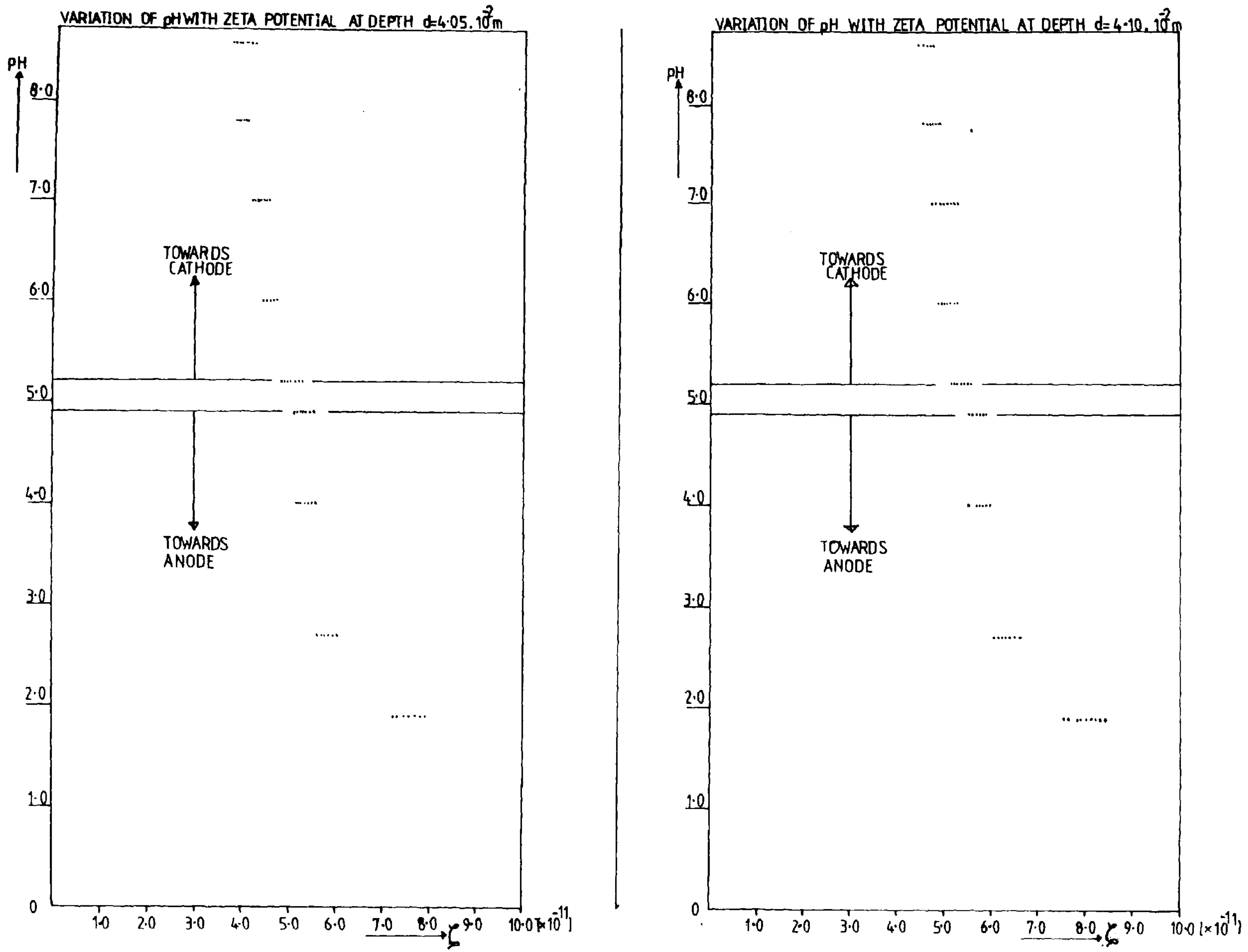
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d= 3{\cdot}85.10^{-2}$ m

FIGURE. 7.38


VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}90.10^{-2}$m

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}95.10^{-2}$m

FIGURE. 7. 39



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}05.10^{-2}m$

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}10.10^{-2}m$

FIGURE. 7.40

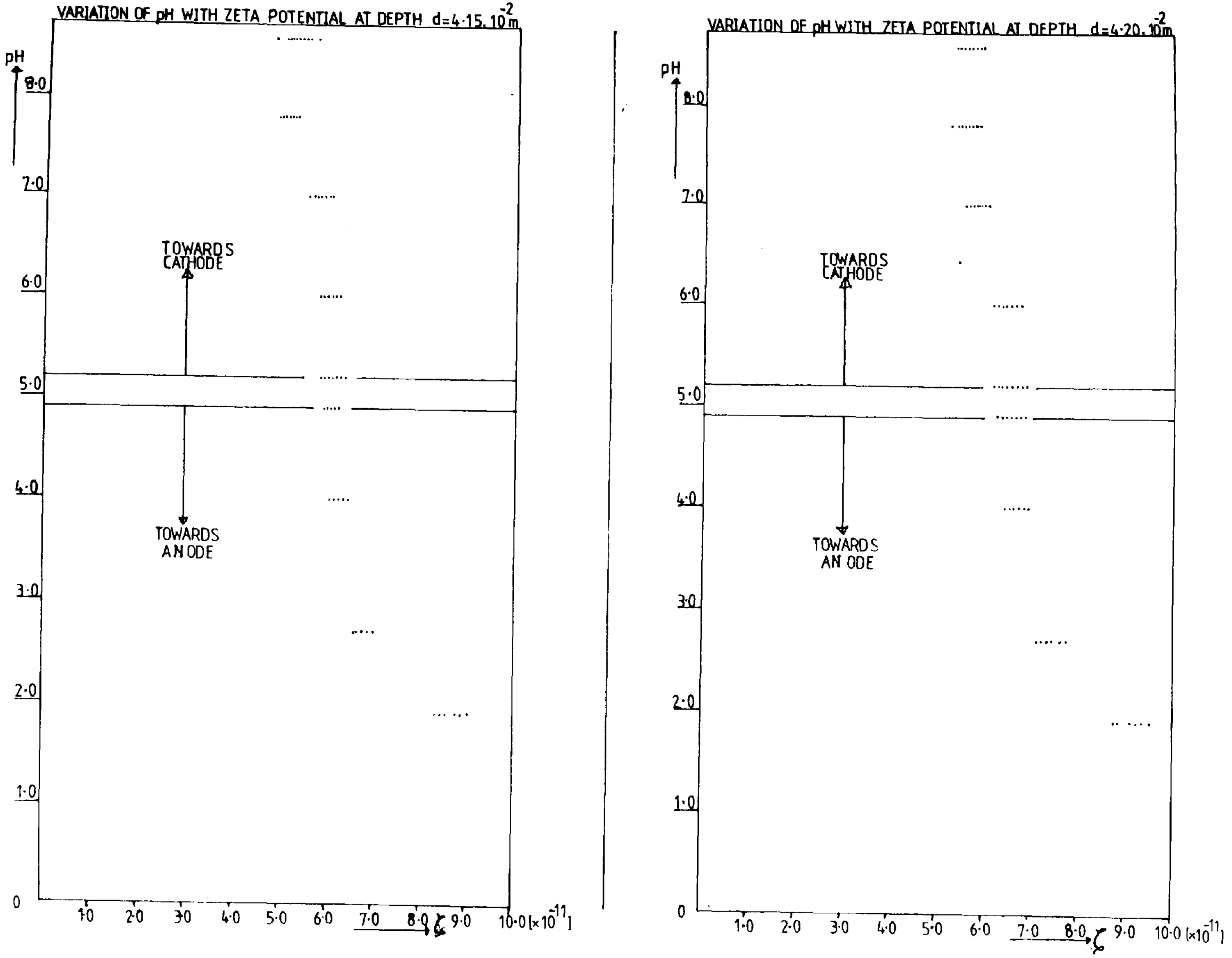
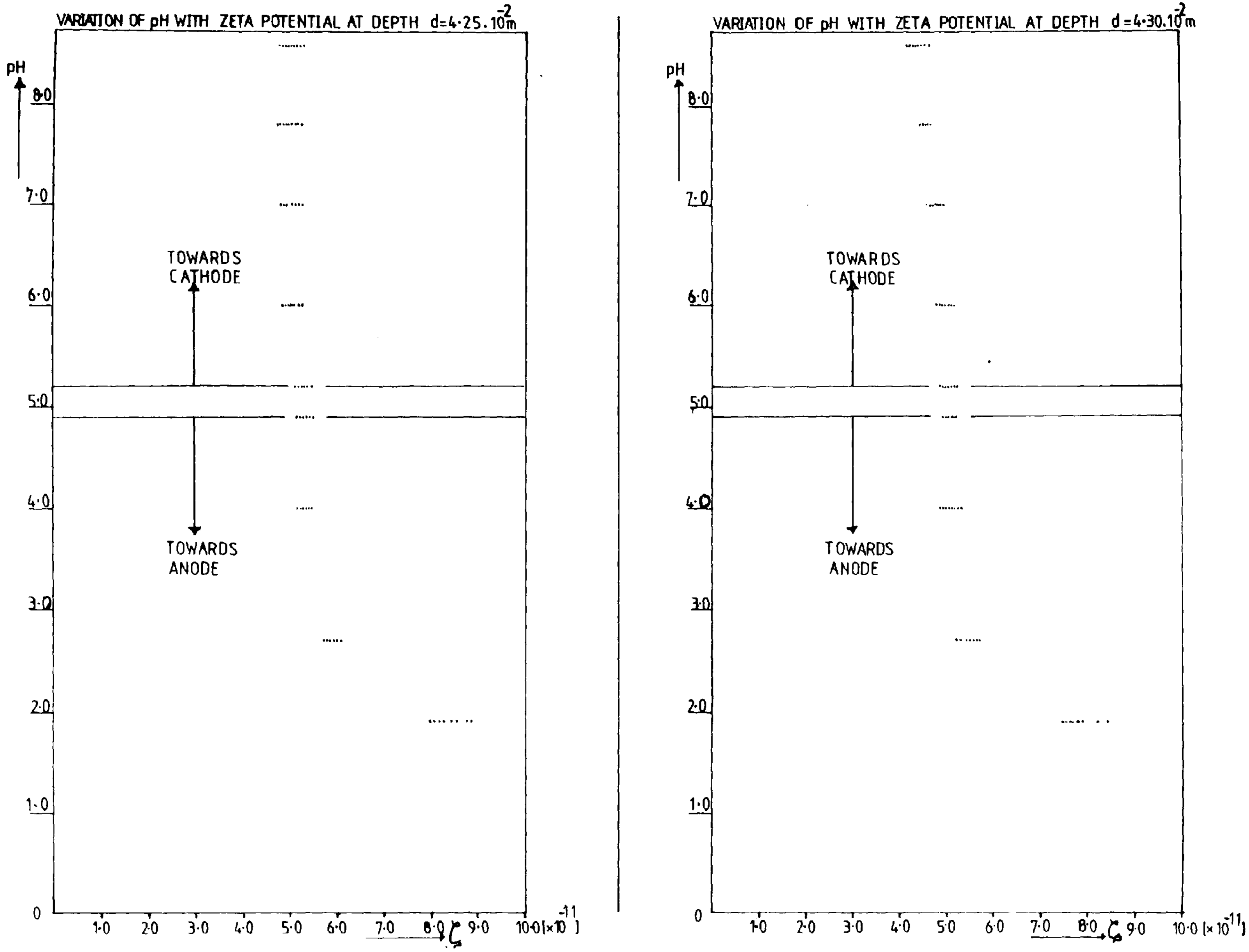

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·15.10^{-2}m
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS CATHODE
TOWARDS ANODE
1·0
2·0
3·0
4·0
5·0
6·0
7·0
8·0
9·0
10·0 [×10^{-11}]
ζ
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·20.10^{-2}m
pH
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
TOWARDS CATHODE
TOWARDS ANODE
1·0
2·0
3·0
4·0
5·0
6·0
7·0
8·0
9·0
10·0 [×10^{-11}]
ζ

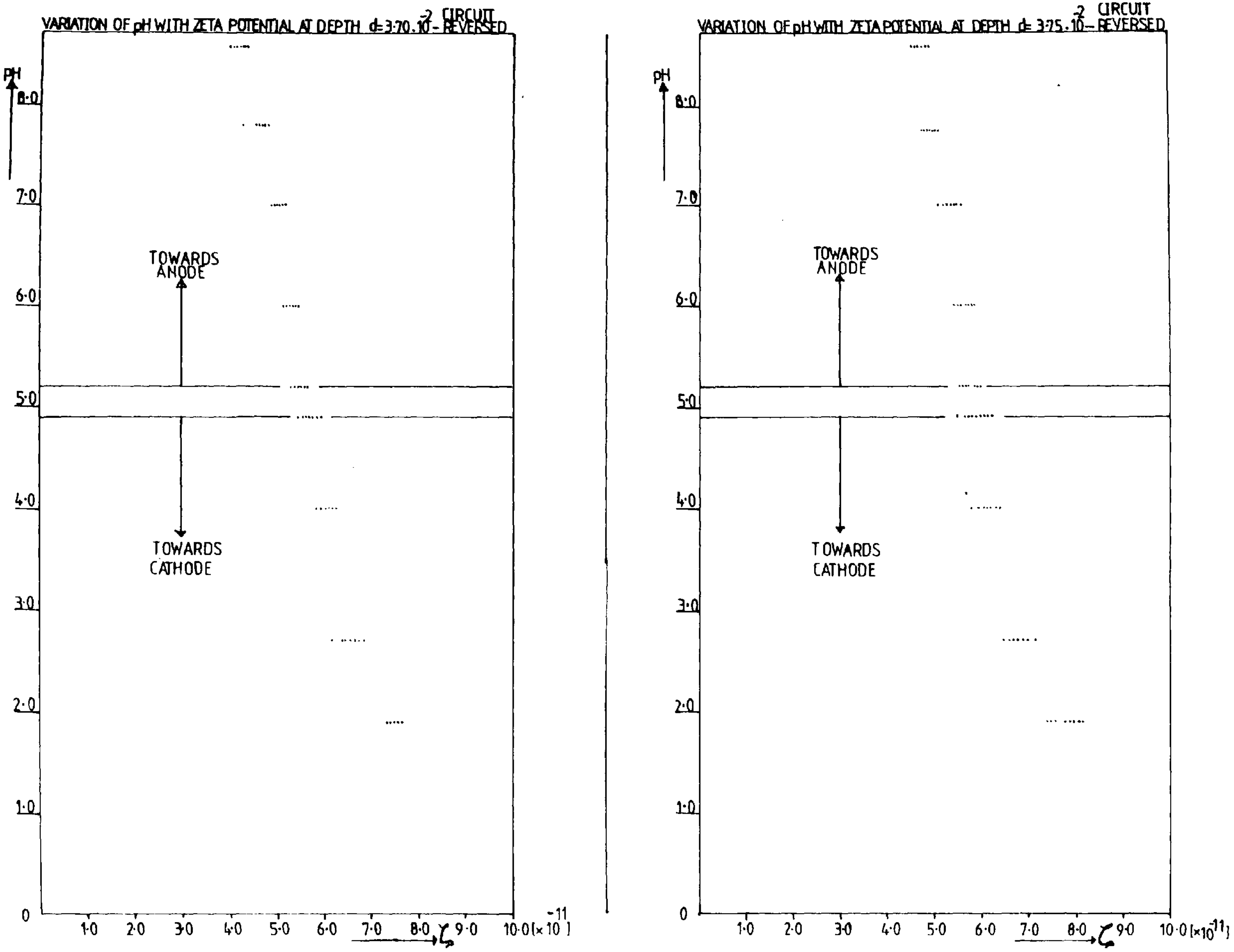
FIGURE. 7.41



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}25.10^{-2}m$

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}30.10^{-2}m$

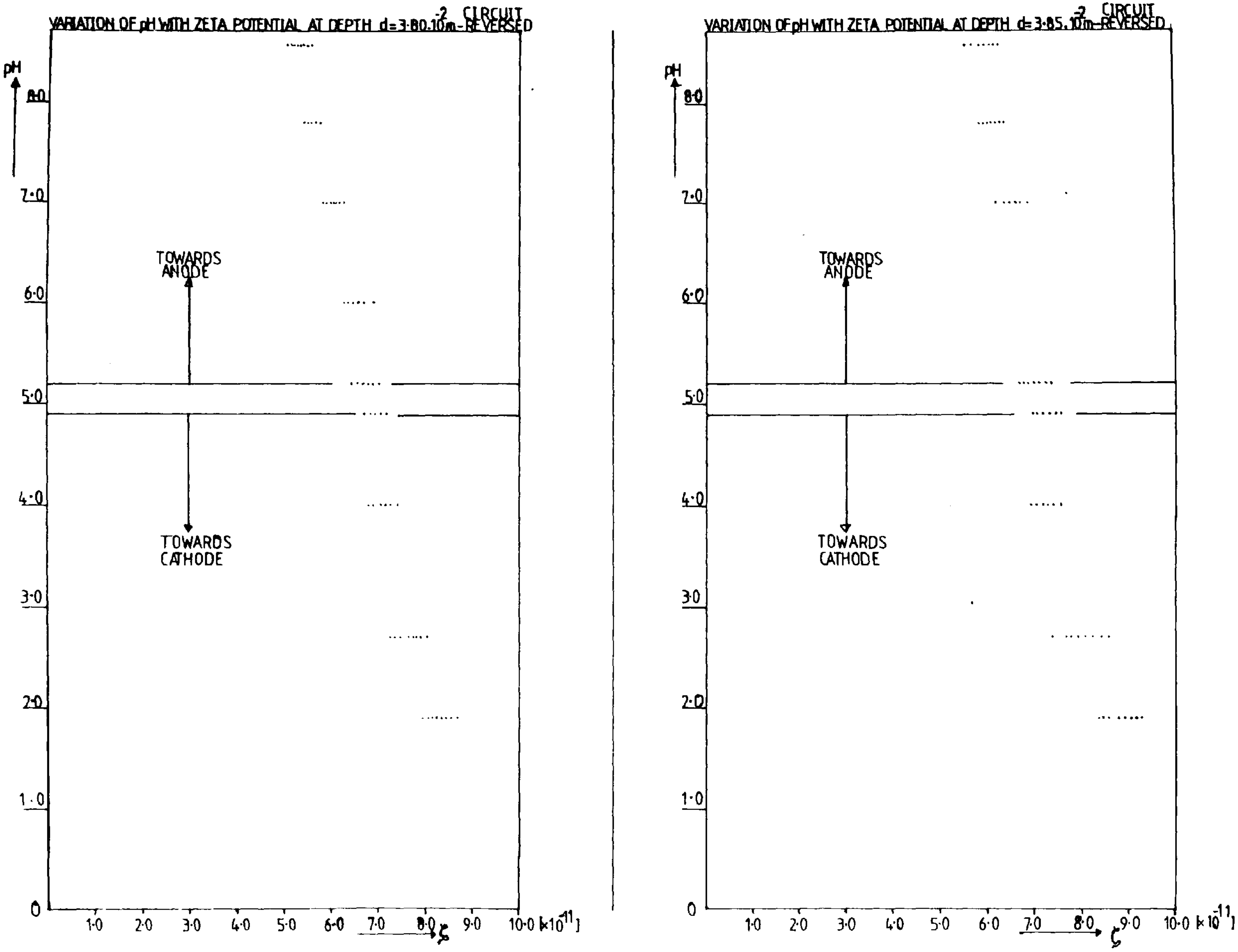
FIGURE. 7.42



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}70.10^{-2}$ - CIRCUIT REVERSED

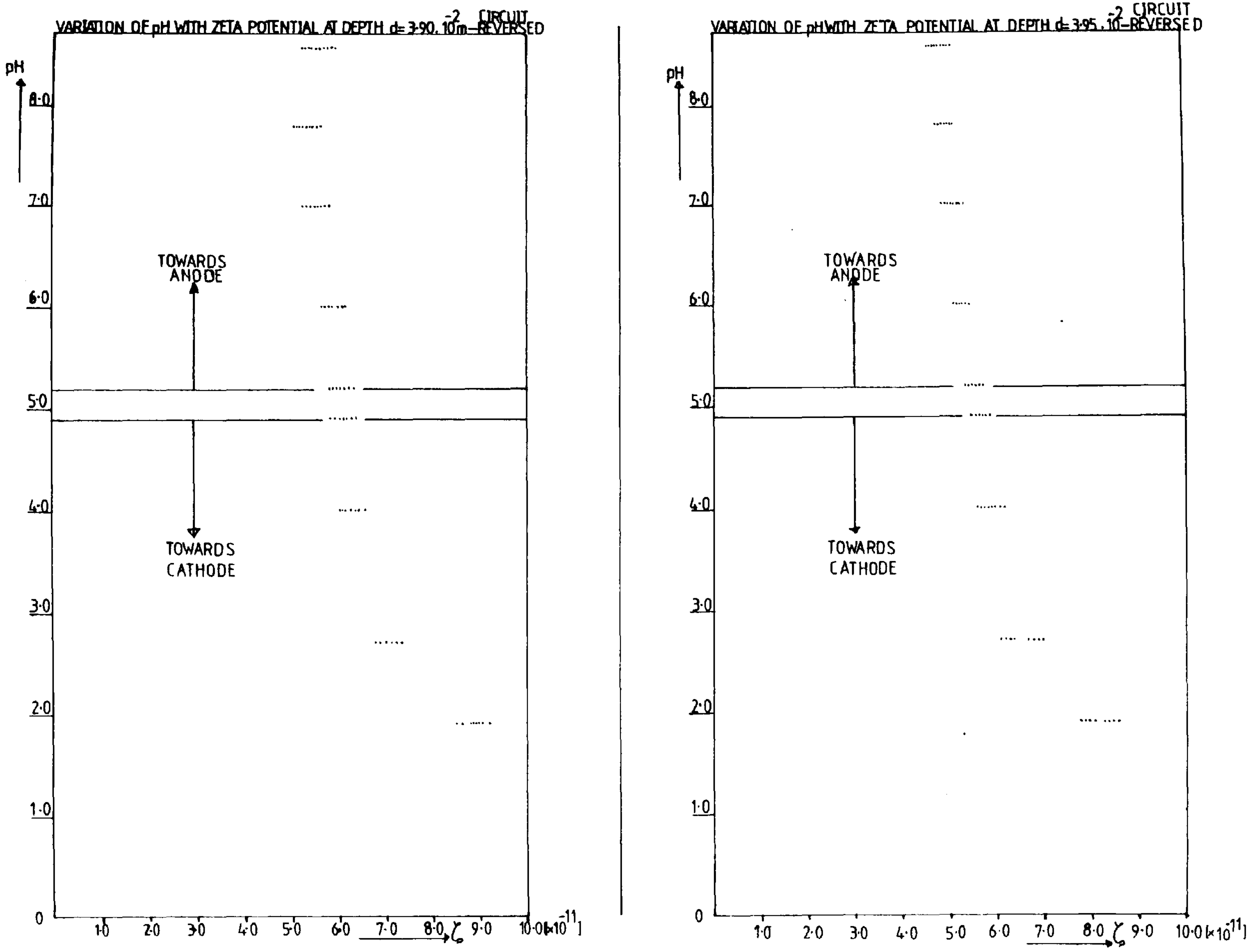
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}75.10^{-2}$ - CIRCUIT REVERSED

FIGURE. 7.43


VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=3·80.10^{-2}m- CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=3·85.10^{-2}m- CIRCUIT REVERSED

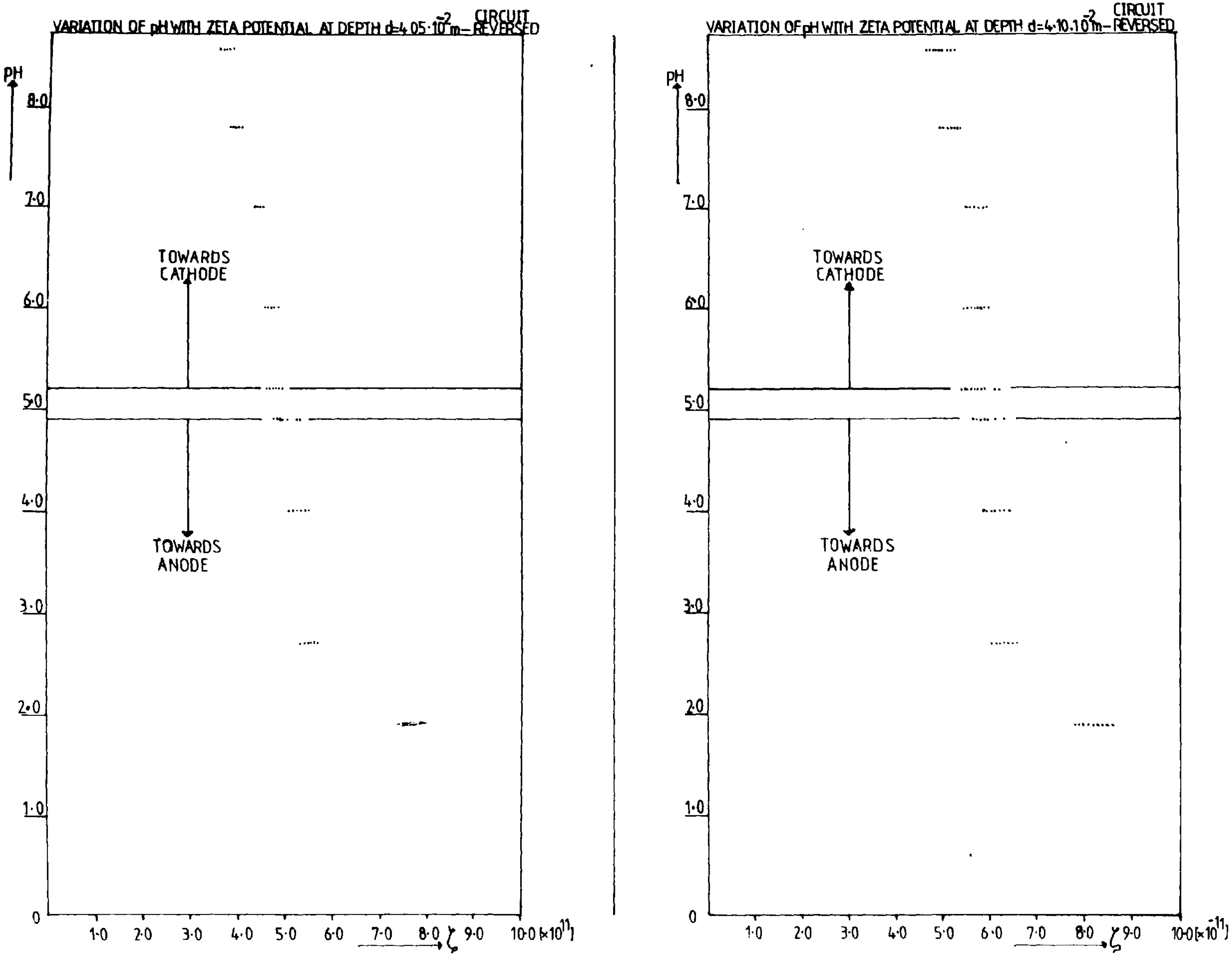
FIGURE. 7.44



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d = 3{\cdot}90.10^{-2}$m CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d = 3{\cdot}95.10^{-2}$ CIRCUIT REVERSED

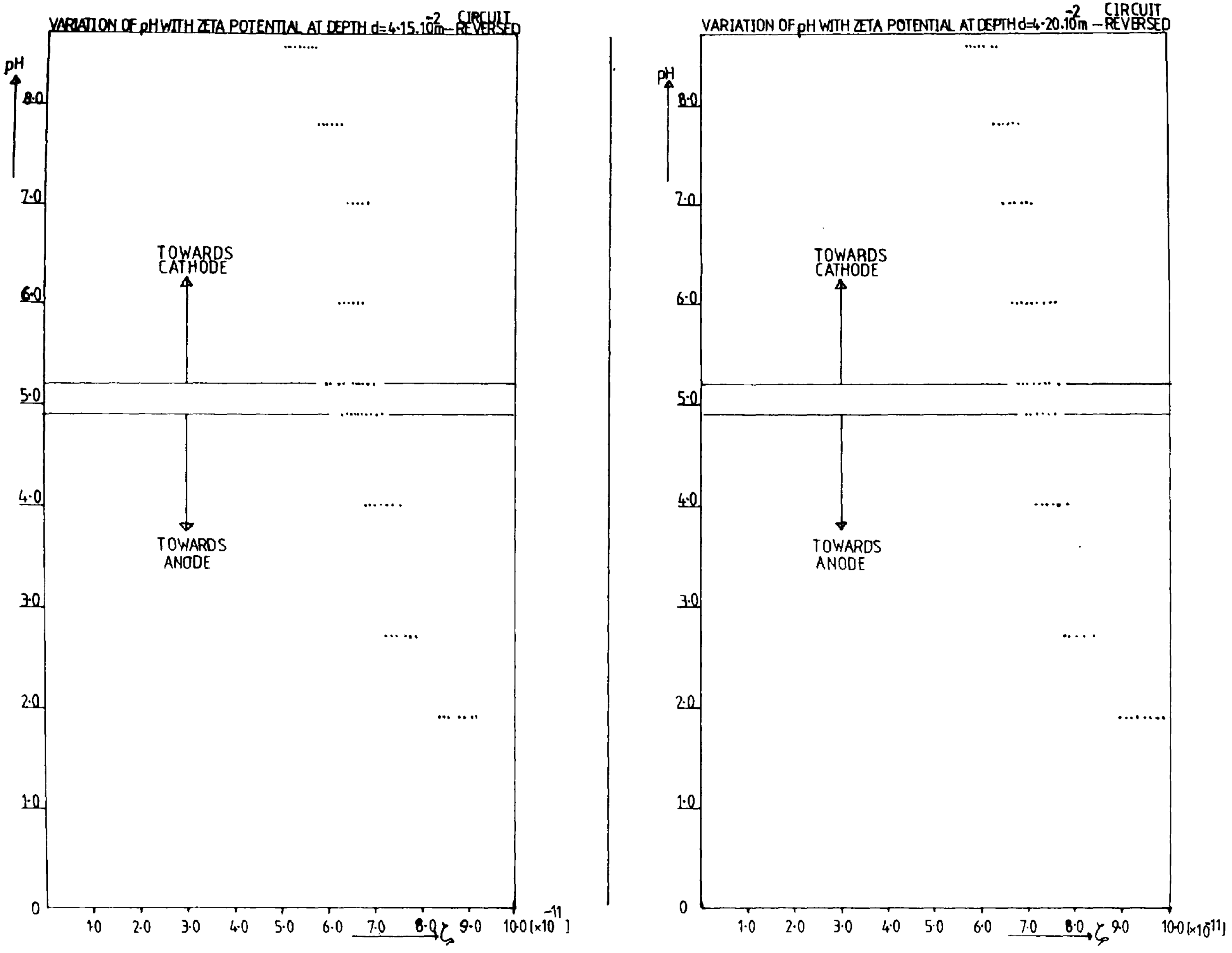
FIGURE. 7.45



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}05{\cdot}10^{-2}$m– CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}10.10^{-2}$m– CIRCUIT REVERSED

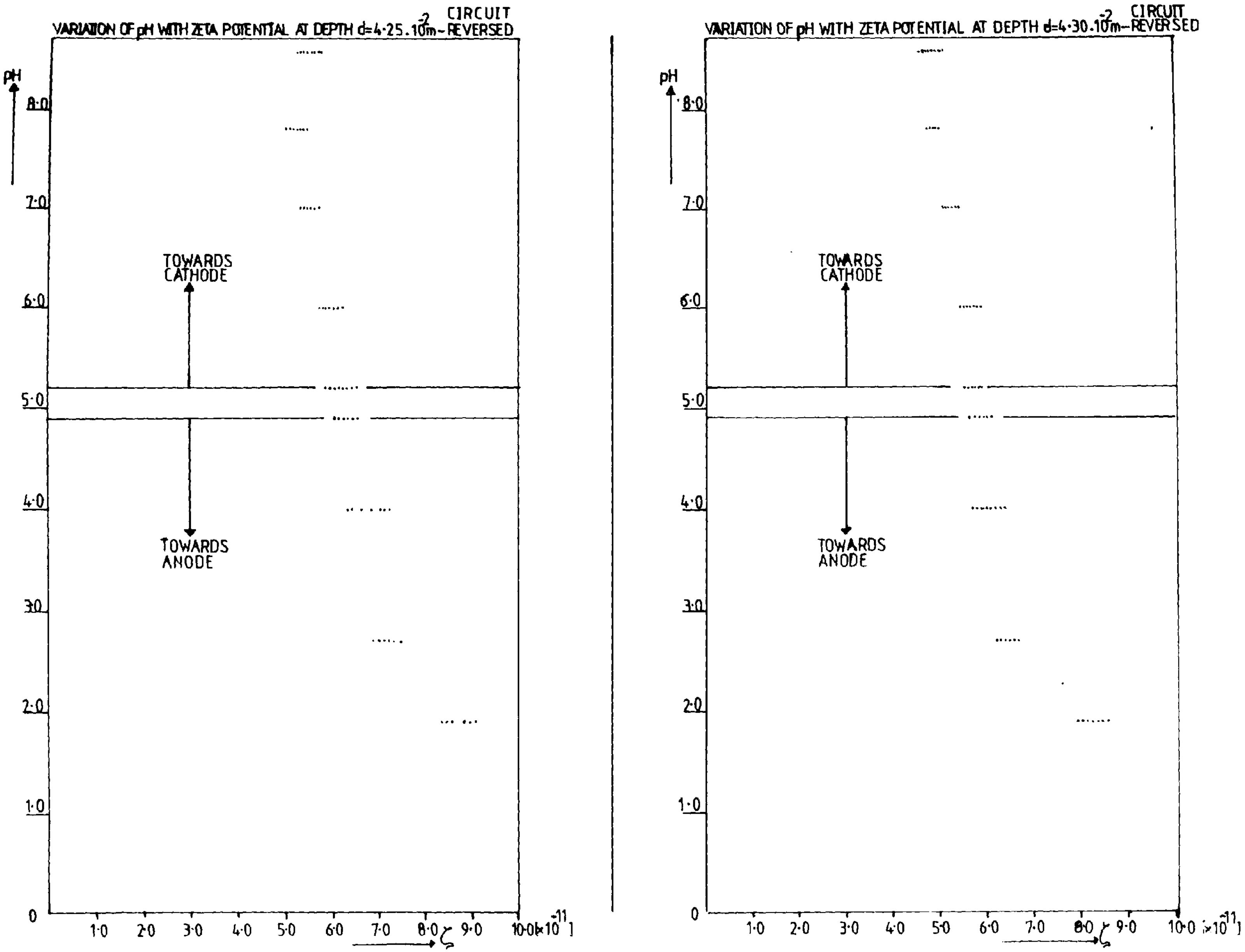
FIGURE. 7.46



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}15.10^{-2}$m – CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}20.10^{-2}$m – CIRCUIT REVERSED

FIGURE.7.47



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·25.10^{-2}m–CIRCUIT REVERSED

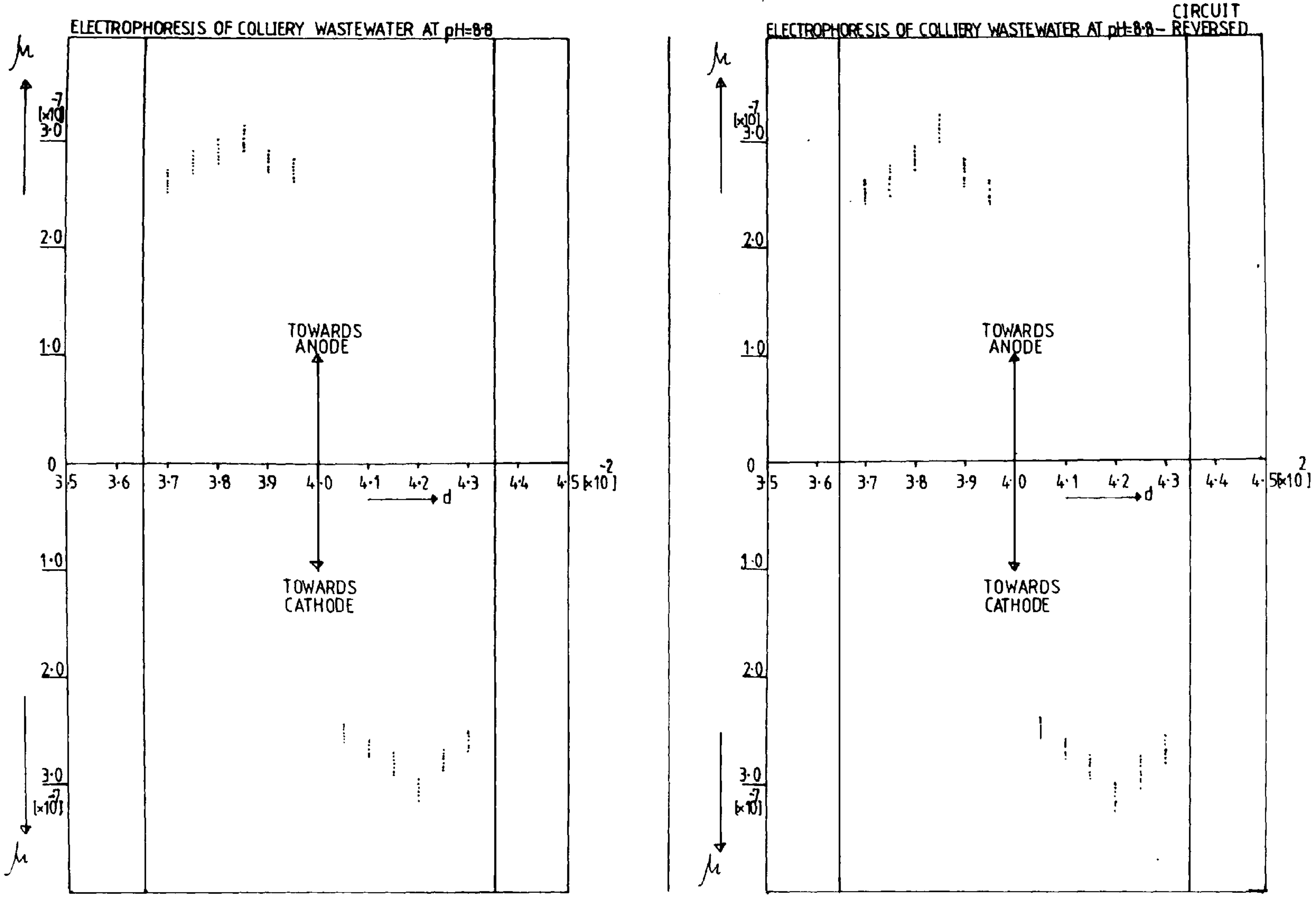
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·30.10^{-2}m–CIRCUIT REVERSED

7.5 ELECTROPHORESIS OF COLLIERY WASTE-WATER - H_2SO_4

The graphs of the mobility profiles at different pH values against the various levels of depth within the electrophoretic cell using sulphuric acid compared favourably with those using hydrochloric acid. These graphs can be seen on Figures 7.48 to 7.54.

The variation of pH with electrophoretic mobility and zeta potential at the same depth in the electrophoretic cell also illustrated the same graphical shapes (see Figures 7.55 to 7.78) except that between pH values of 5.3 and 5.0, the particles moved towards both the anode and cathode whilst the others were virtually at rest or moving in all directions. Then at pH values of 5.0 or less the particles at the various depths within the electrophoretic cell moved in opposite direction (charge reversal). Hence the iso-electric point and the zero point of charge were determined to be at pH = 5.0, which agreed favourably with the results obtained in using hydrochloric acid.

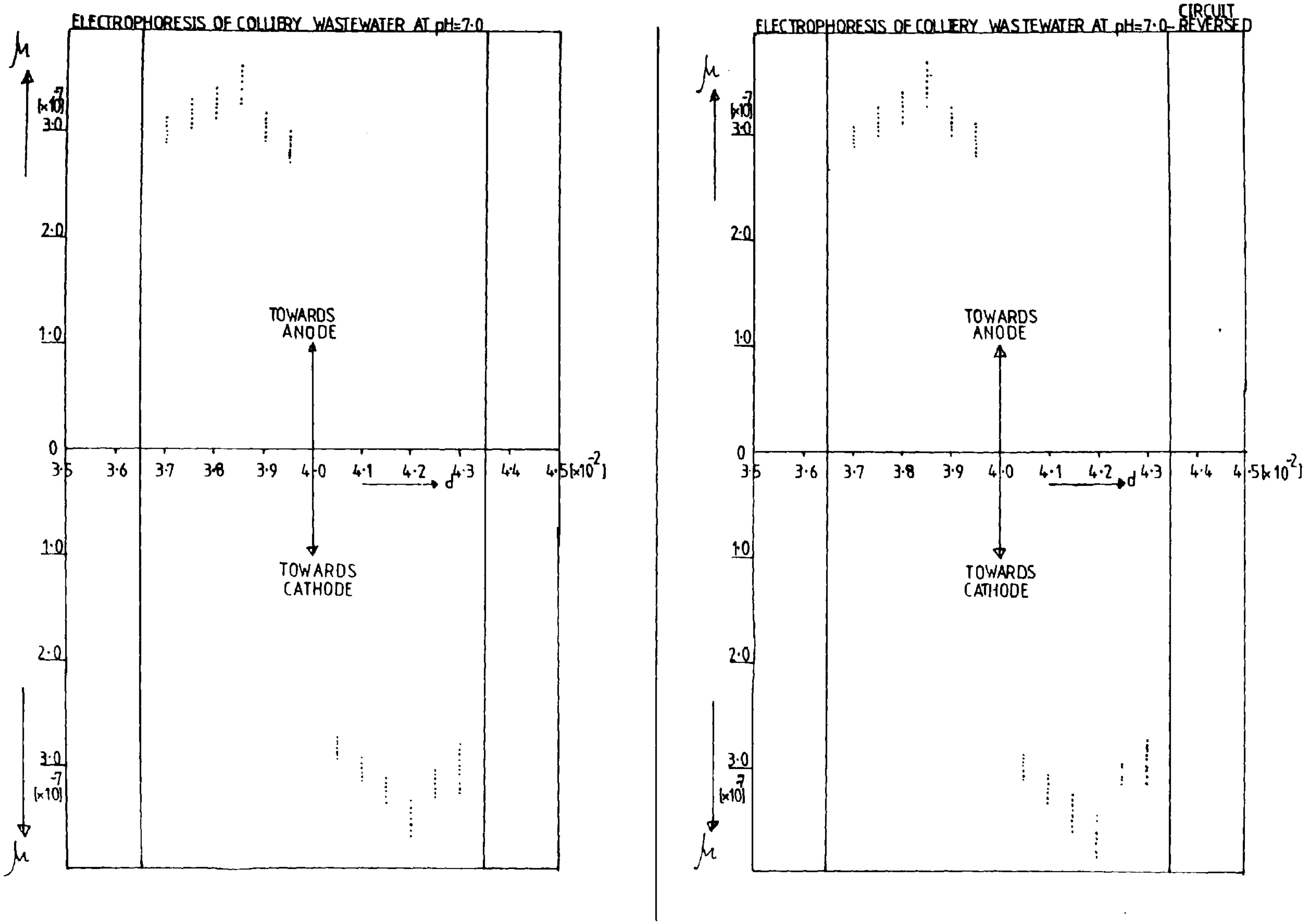
FIGURE.7.48



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=8·8

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=8·8– CIRCUIT REVERSED

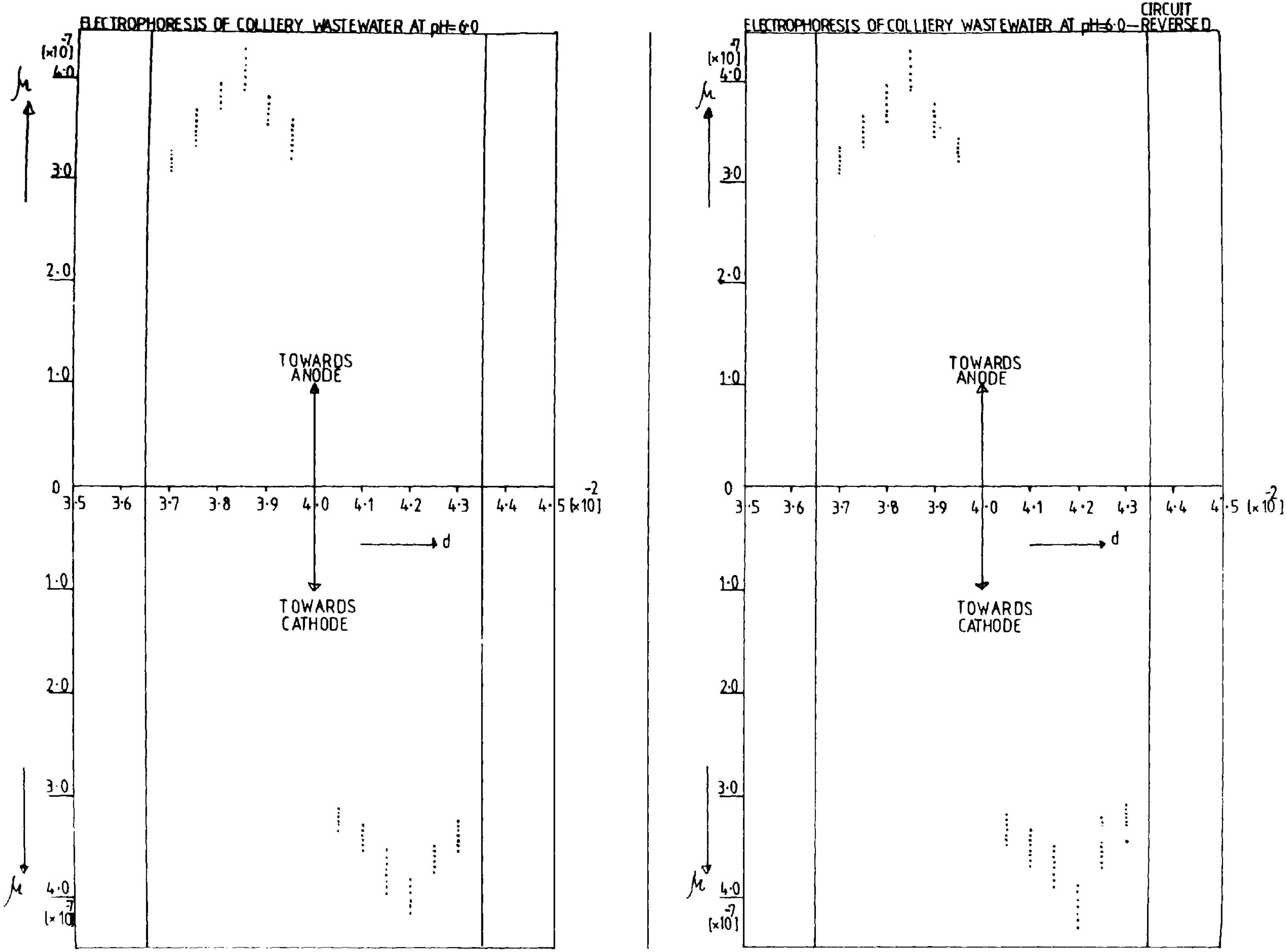
FIGURE.7.49



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·0

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=7·0– CIRCUIT REVERSED

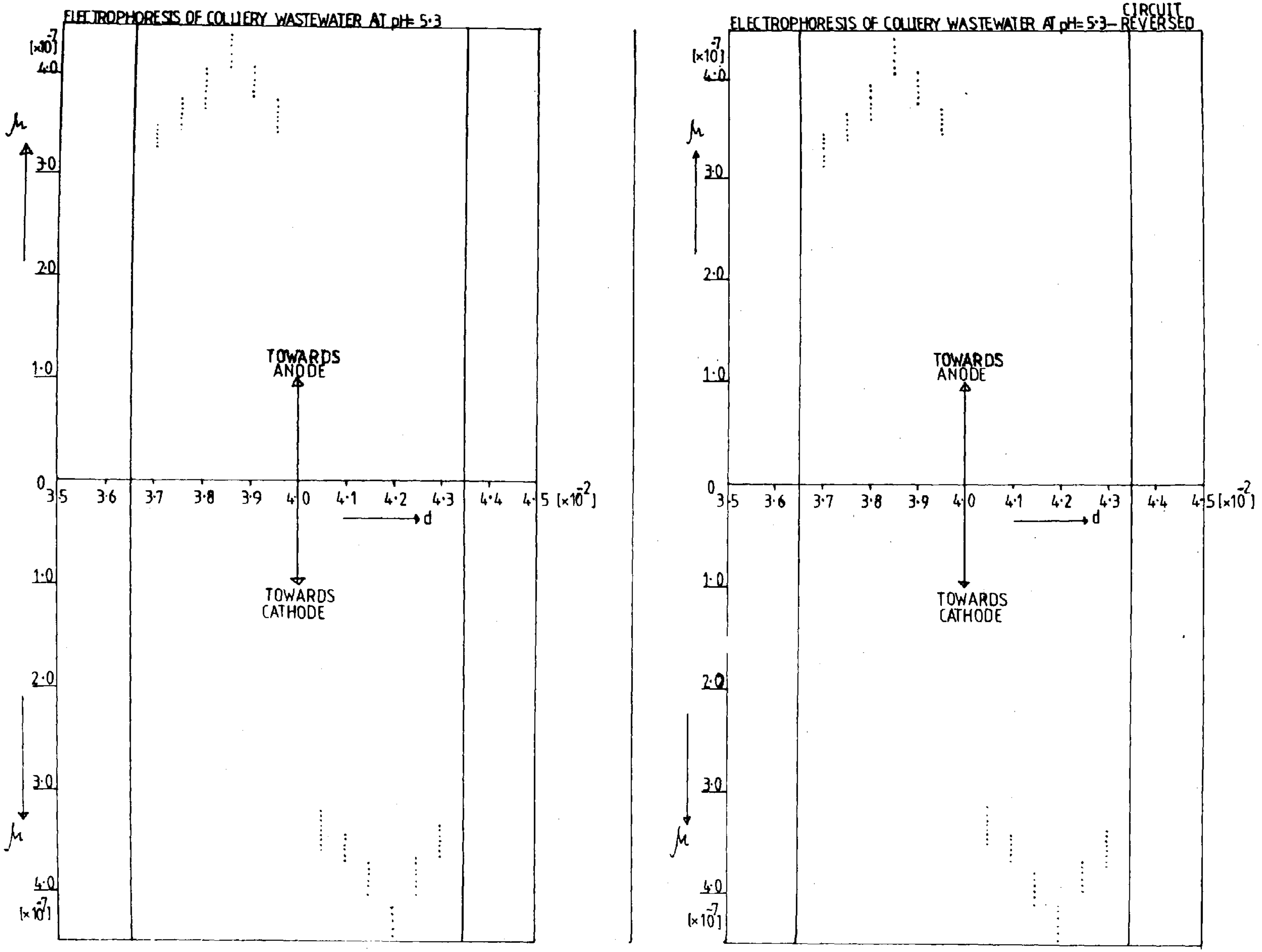
FIGURE. 7.50



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=6·0

CIRCUIT
ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=6·0—REVERSED

FIGURE. 7.51



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 5·3

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 5·3— CIRCUIT REVERSED

-176-

FIGURE. 7.52

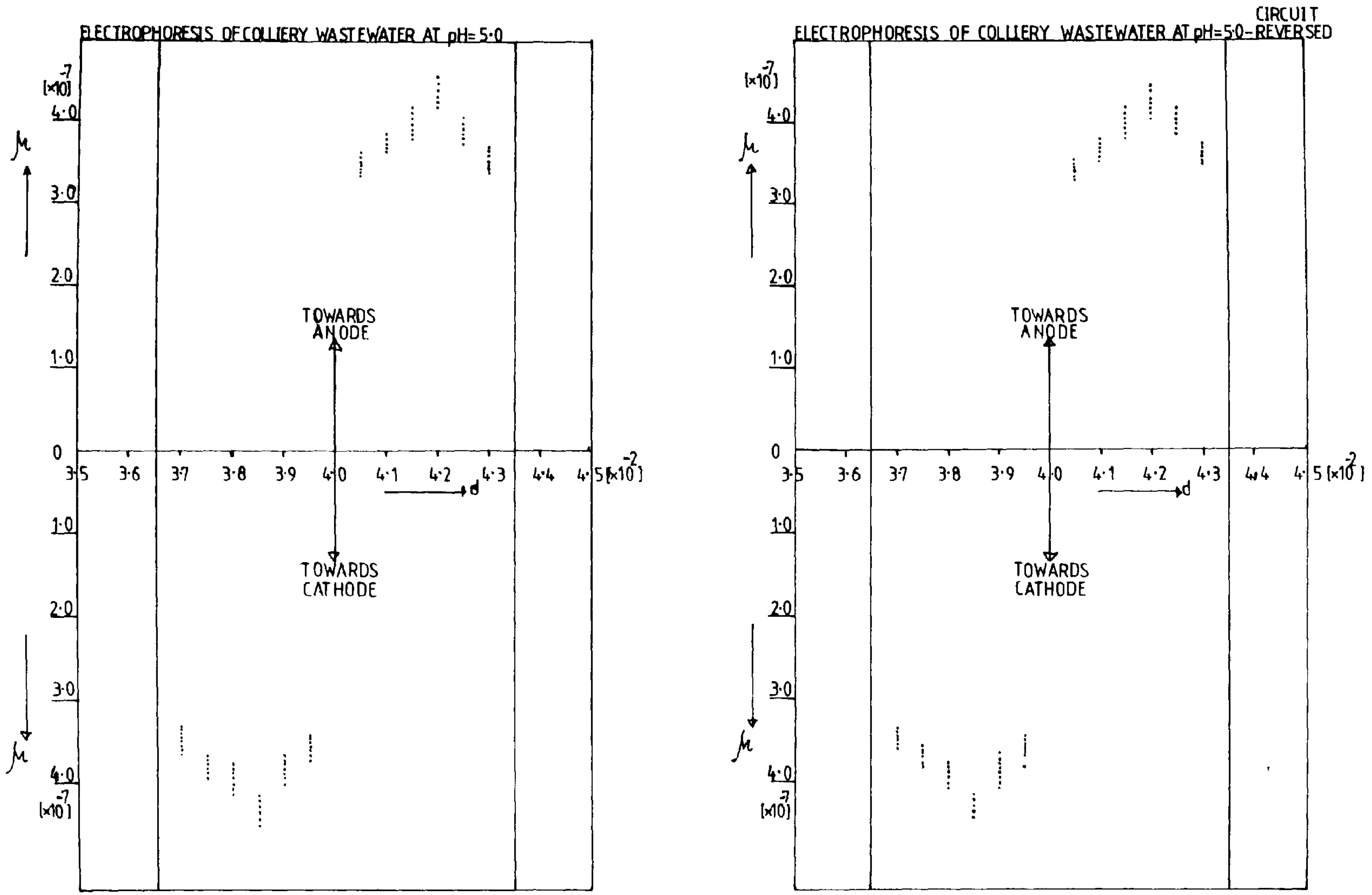

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=5·0
ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=5·0-REVERSED CIRCUIT
μ
[×10^-7]
4·0
3·0
2·0
1·0
0
1·0
2·0
3·0
4·0
3·5
3·6
3·7
3·8
3·9
4·0
4·1
4·2
4·3
4·4
4·5 [×10^-2]
d
TOWARDS ANODE
TOWARDS CATHODE

FIGURE. 7.53

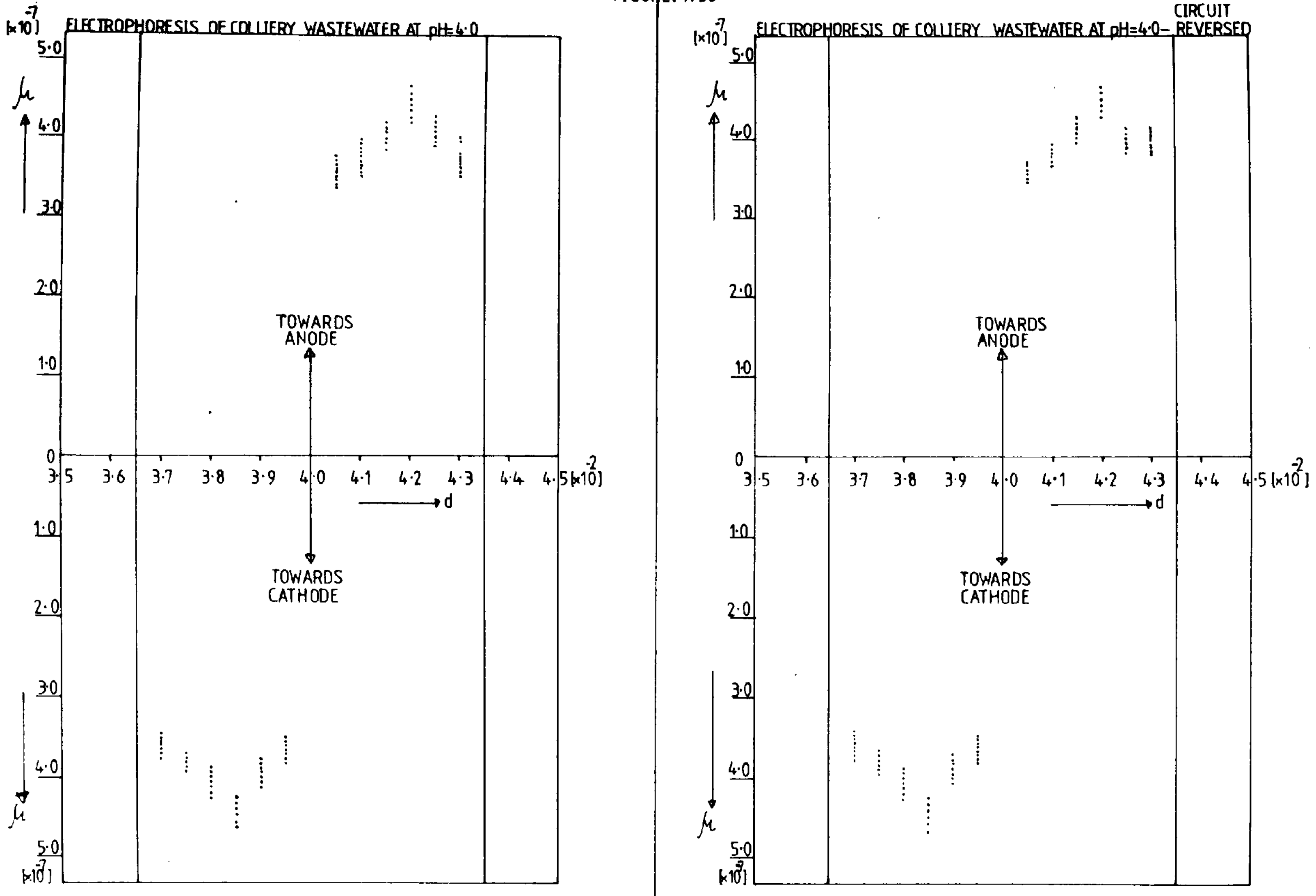
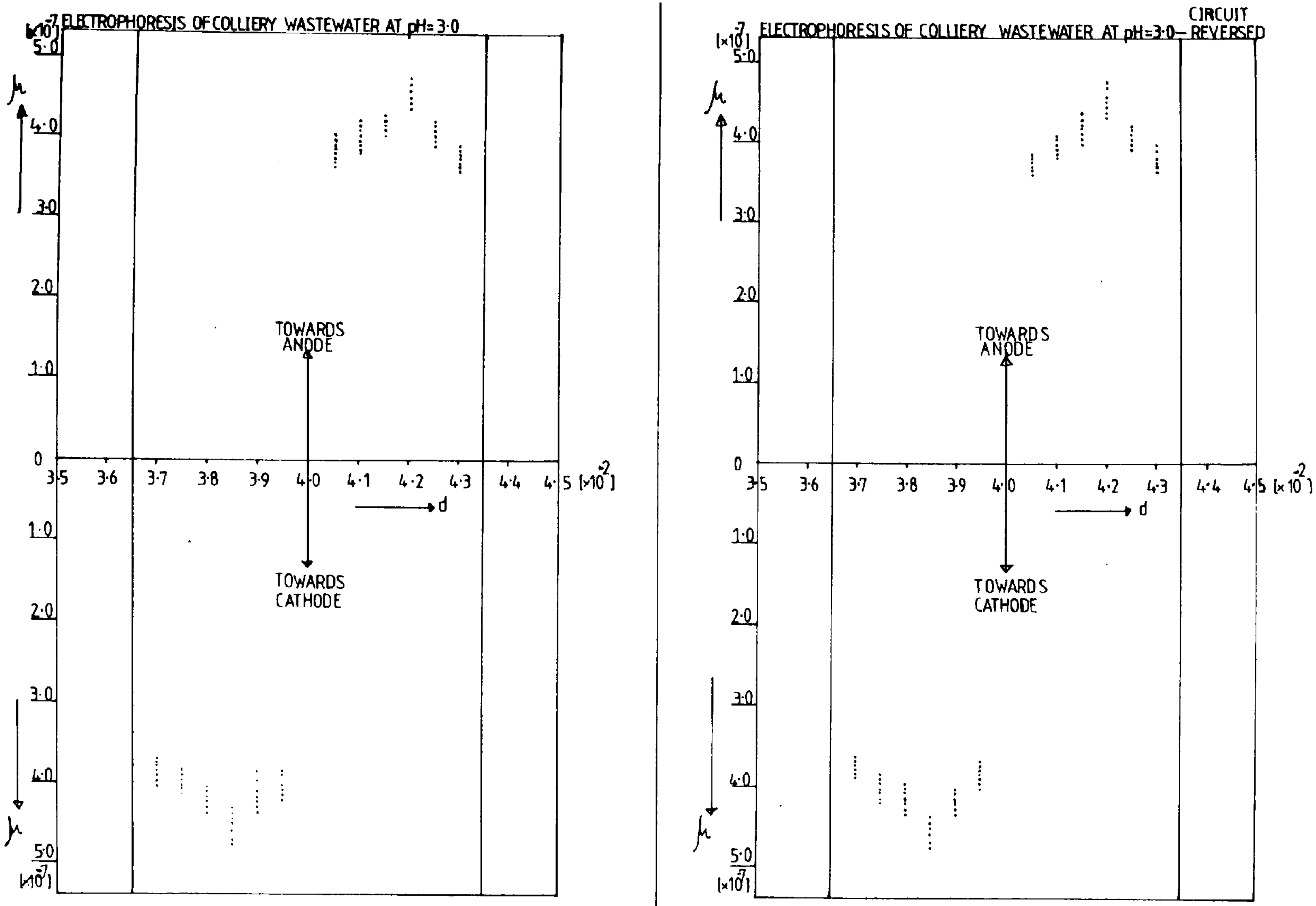

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·0
[×10⁻⁷]
μ
5·0
4·0
3·0
2·0
1·0
0
1·0
2·0
3·0
4·0
5·0
3·5
3·6
3·7
3·8
3·9
4·0
4·1
4·2
4·3
4·4
4·5 [×10⁻²]
d
TOWARDS ANODE
TOWARDS CATHODE
ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=4·0– CIRCUIT REVERSED

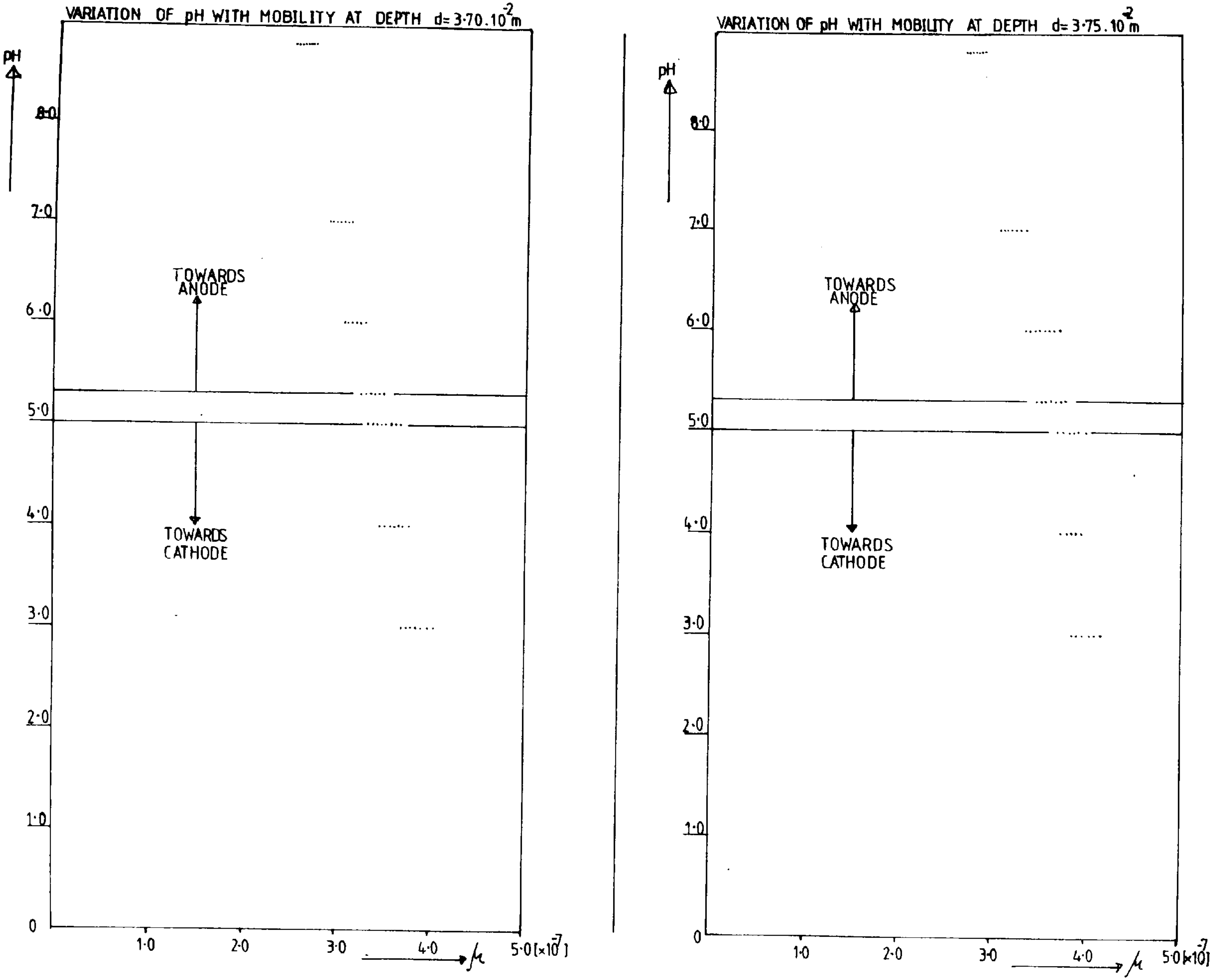
FIGURE. 7. 54



ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH= 3·0

ELECTROPHORESIS OF COLLIERY WASTEWATER AT pH=3·0— CIRCUIT REVERSED

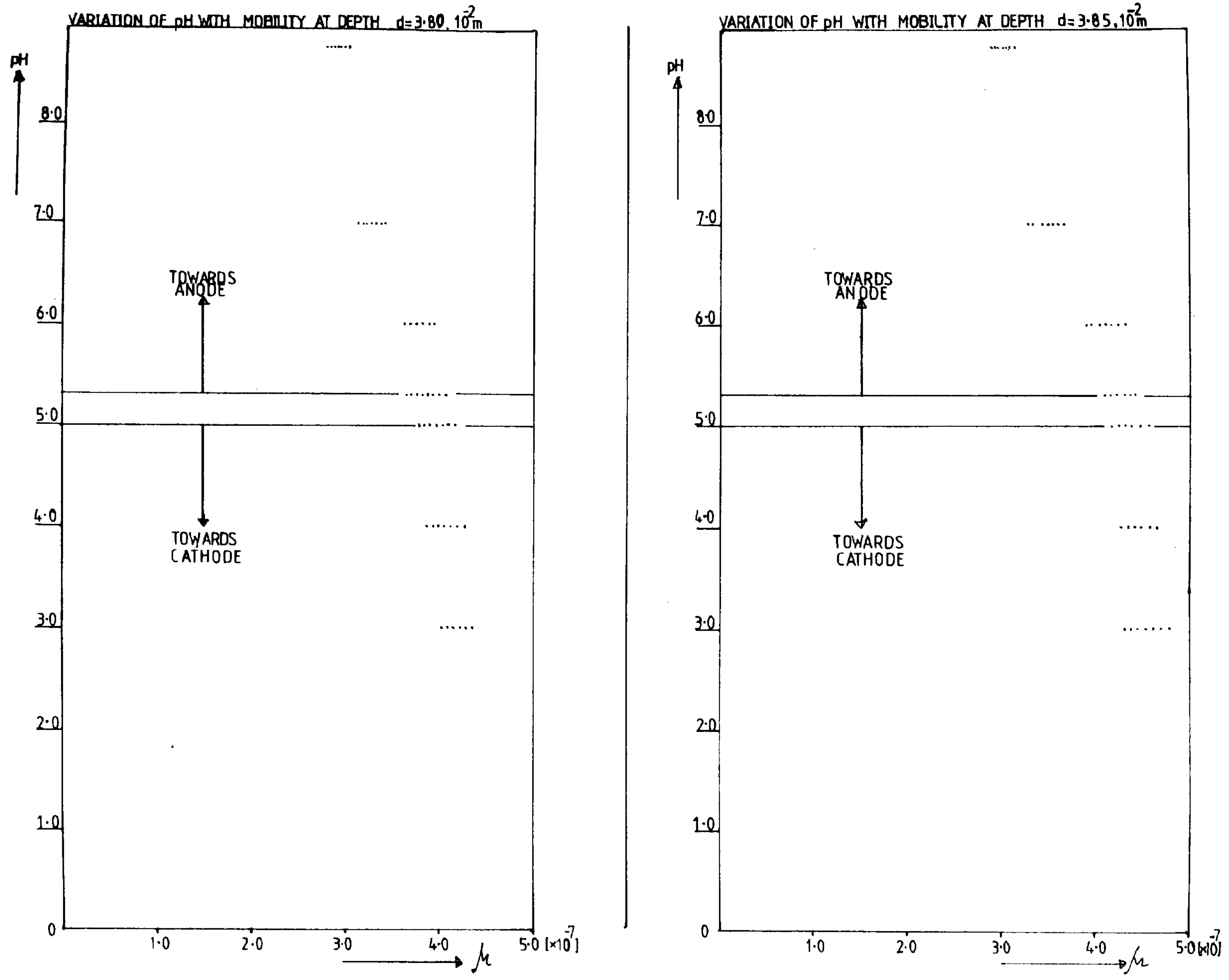
FIGURE. 7.55



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}70.10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}75.10^{-2}$ m

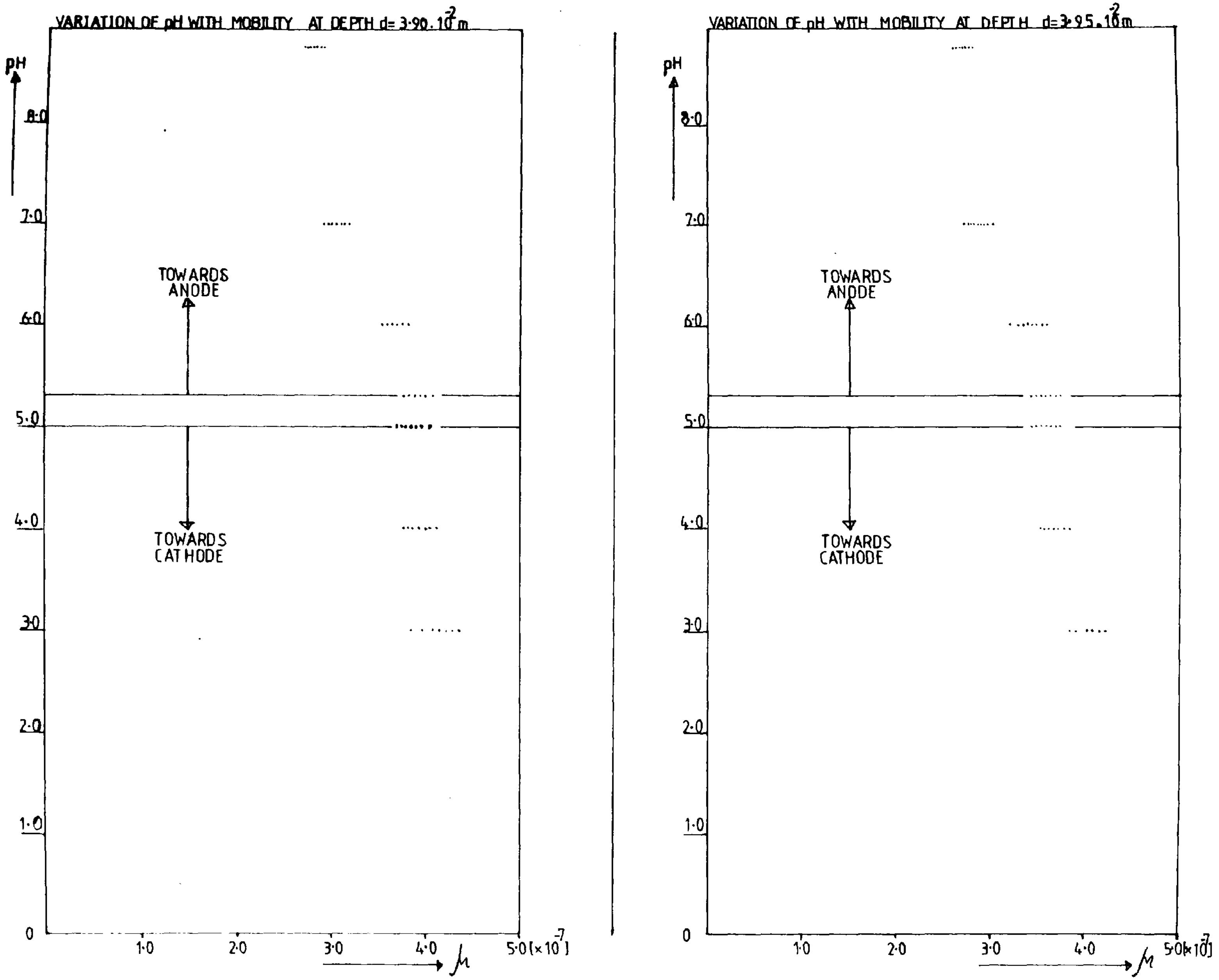
FIGURE. 7.56



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}80 \cdot 10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT DEPTH $d = 3{\cdot}85 \cdot 10^{-2}$ m

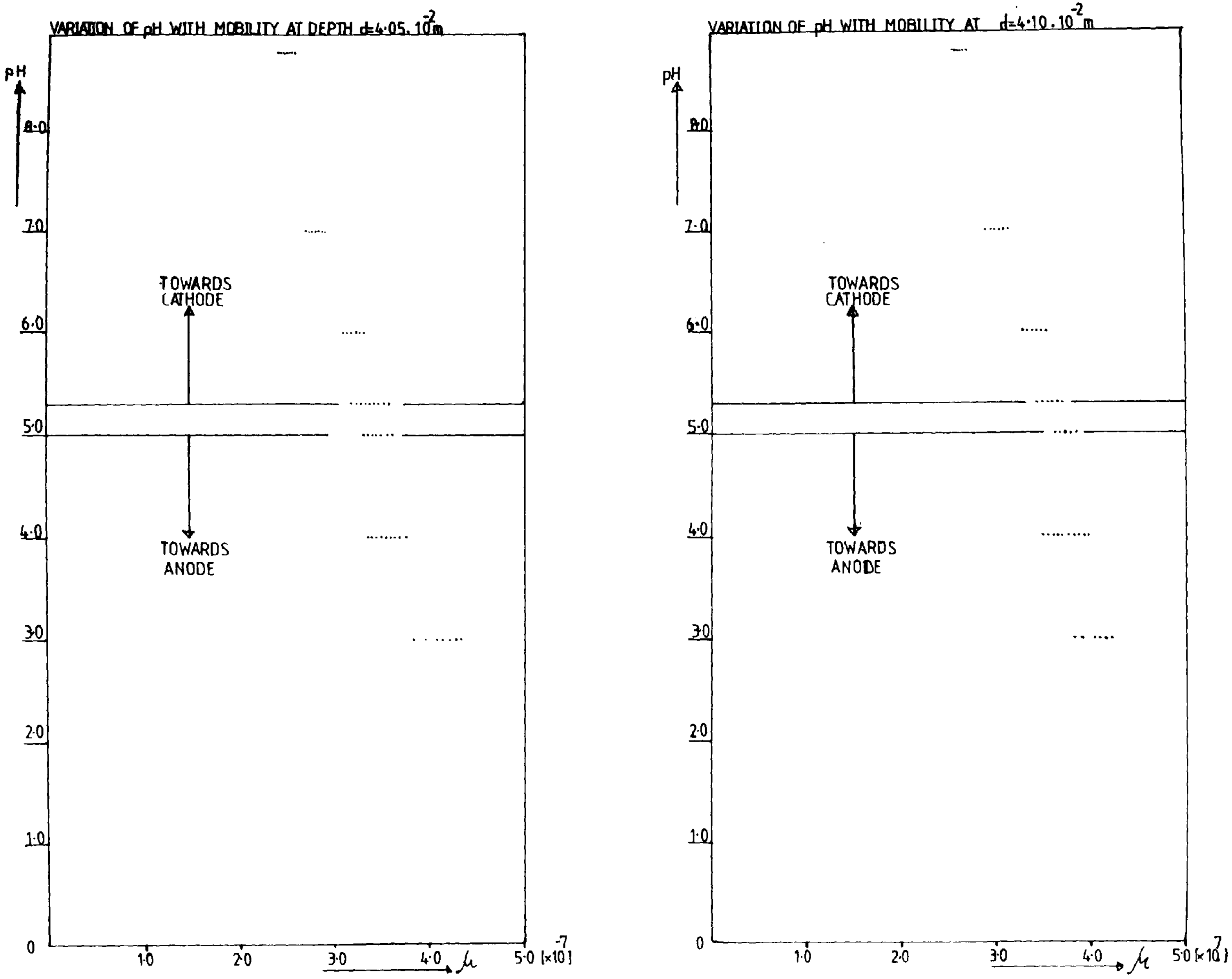
FIGURE.7.57



VARIATION OF pH WITH MOBILITY AT DEPTH d= 3·90.10^{-2}m

VARIATION OF pH WITH MOBILITY AT DEPTH d=3·95.10^{-2}m

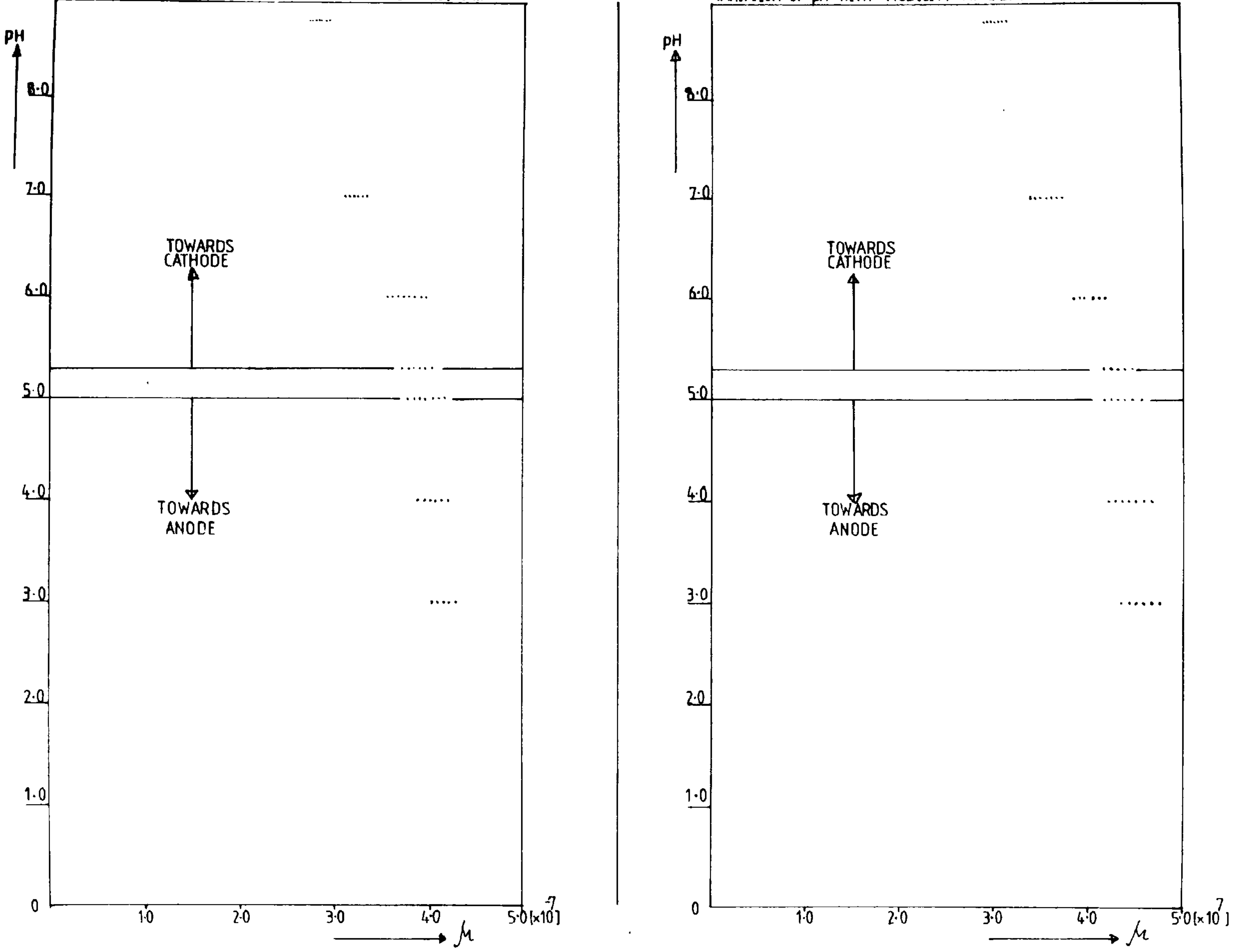
FIGURE. 7.58



VARIATION OF pH WITH MOBILITY AT DEPTH $d = 4{\cdot}05 \cdot 10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT $d = 4{\cdot}10 \cdot 10^{-2}$ m

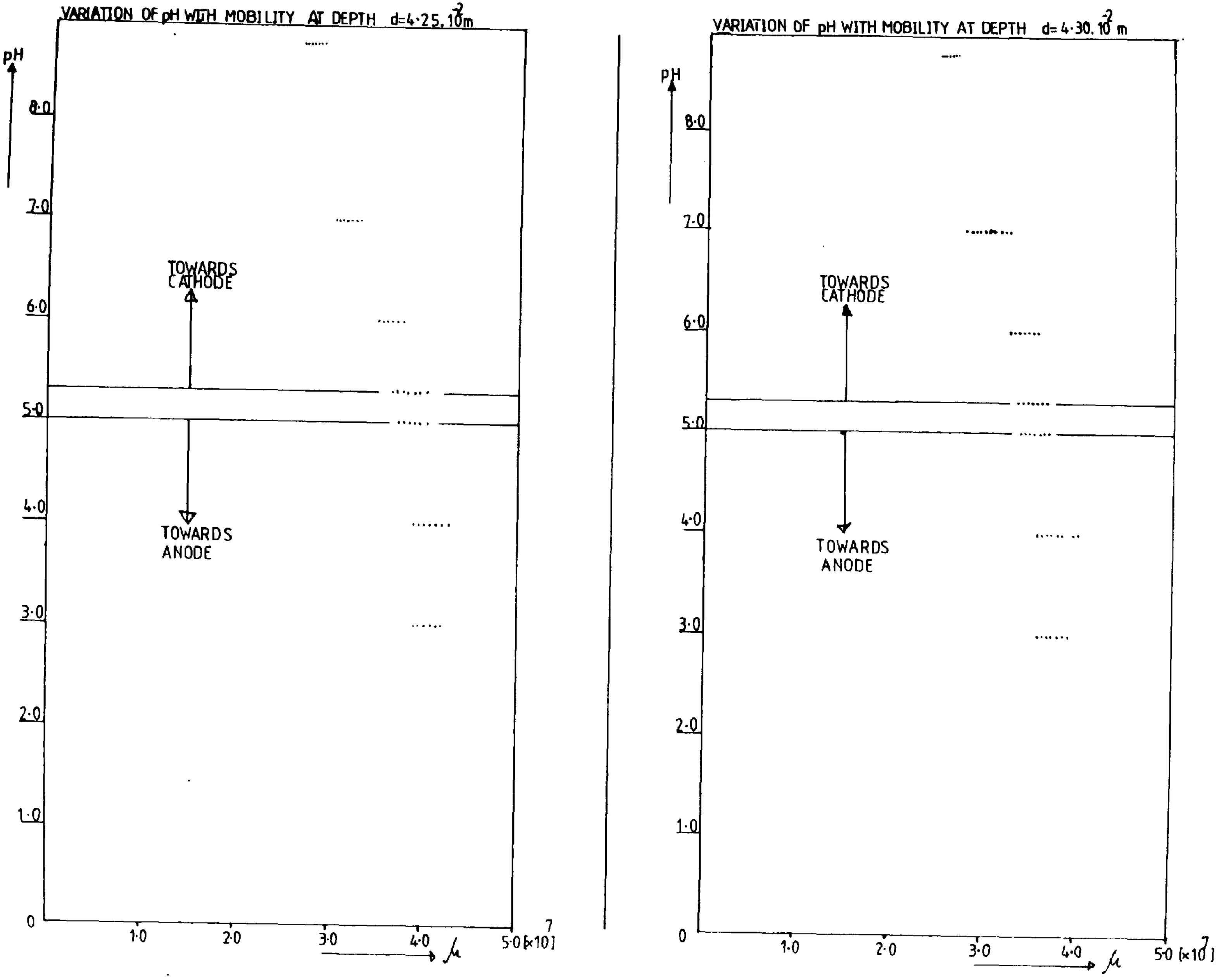
FIGURE. 7. 59



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}15.10^{-2}$m

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4.20.10^{-2}$m

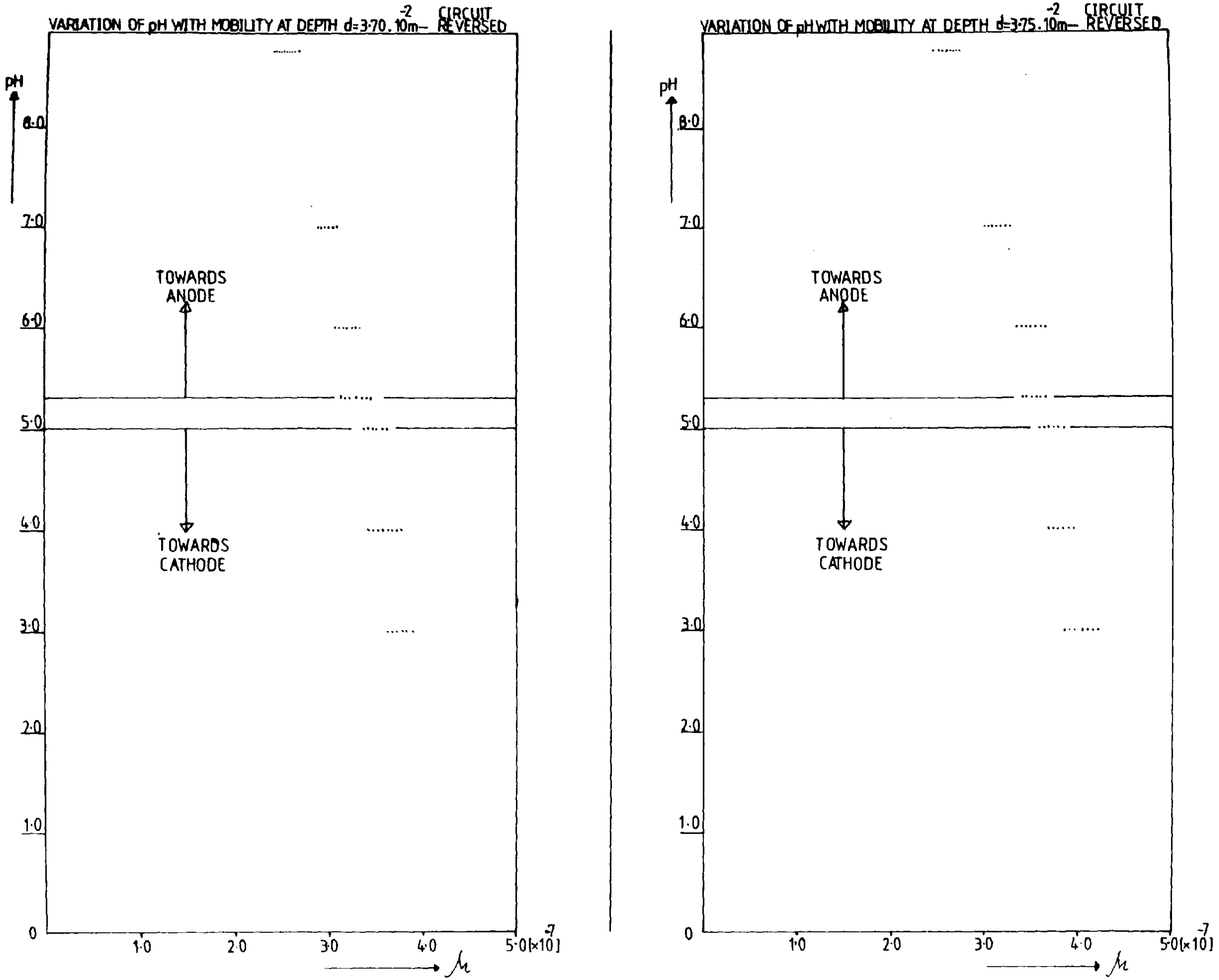
FIGURE. 7.60



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4\cdot25.10^{-2}$ m

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4\cdot30.10^{-2}$ m

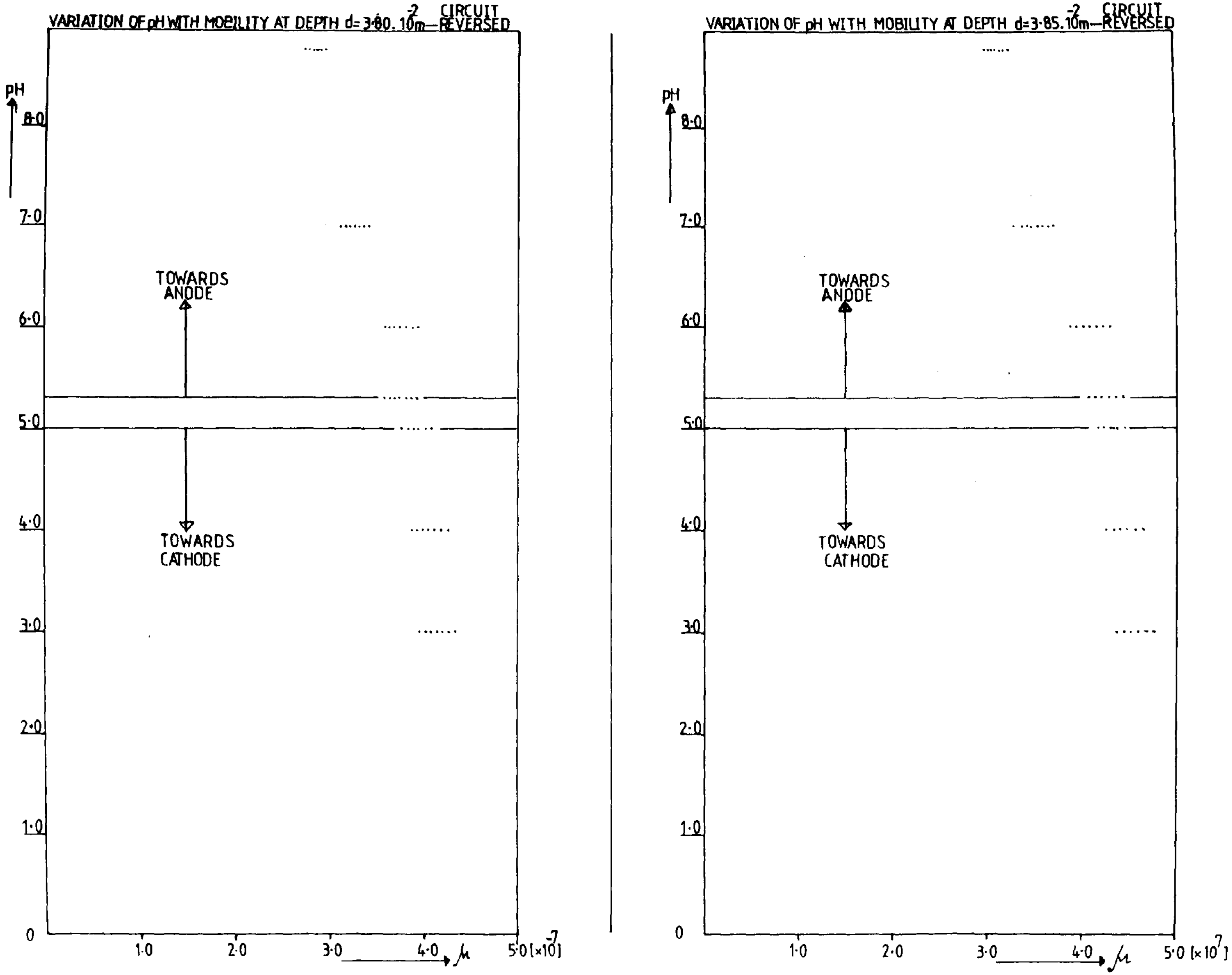
FIGURE. 7.61



VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}70.10^{-2}$m— CIRCUIT REVERSED

VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}75.10^{-2}$m— CIRCUIT REVERSED

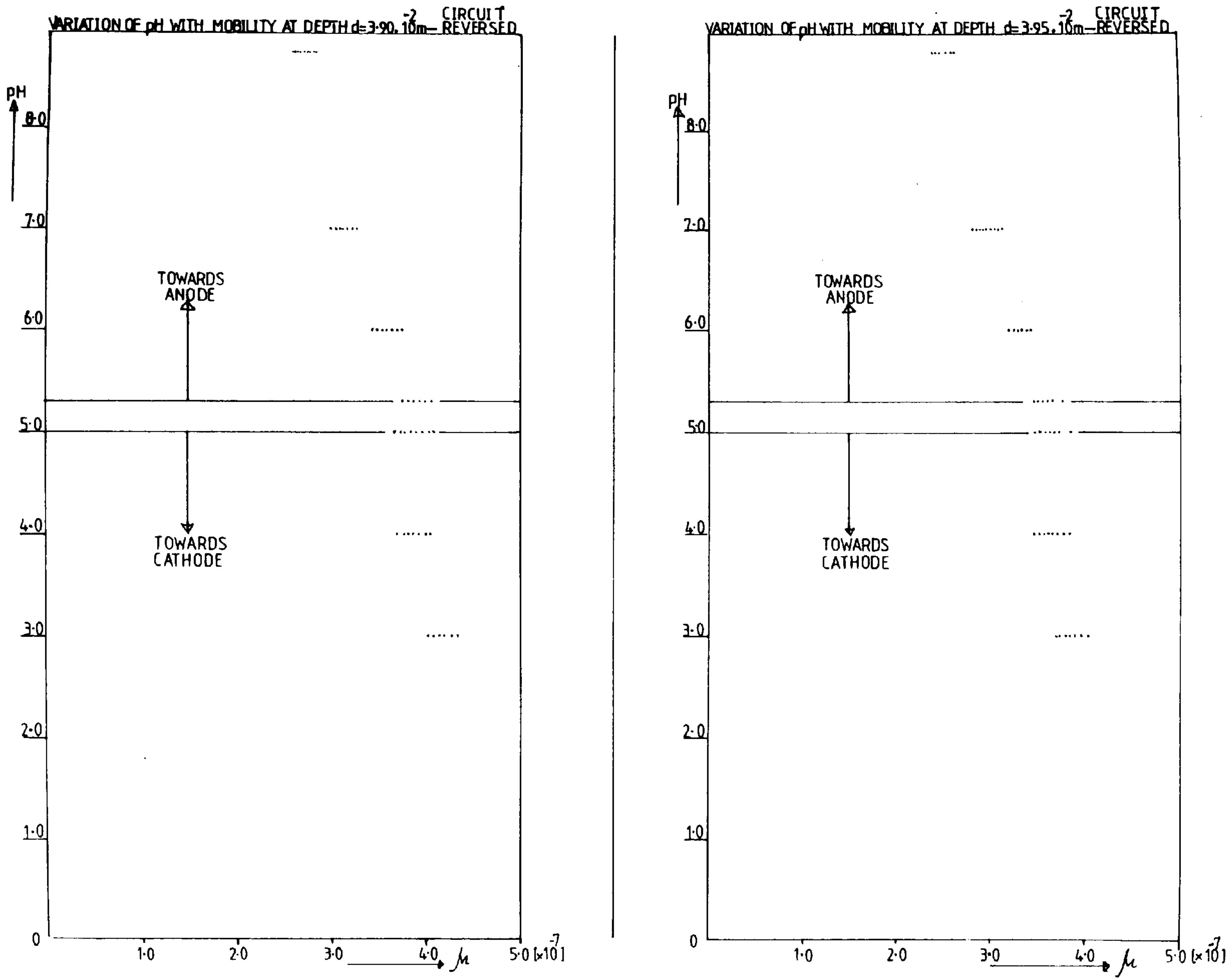
FIGURE. 7.62



VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}80.10^{-2}$m—CIRCUIT REVERSED

VARIATION OF pH WITH MOBILITY AT DEPTH $d=3{\cdot}85.10^{-2}$m—CIRCUIT REVERSED

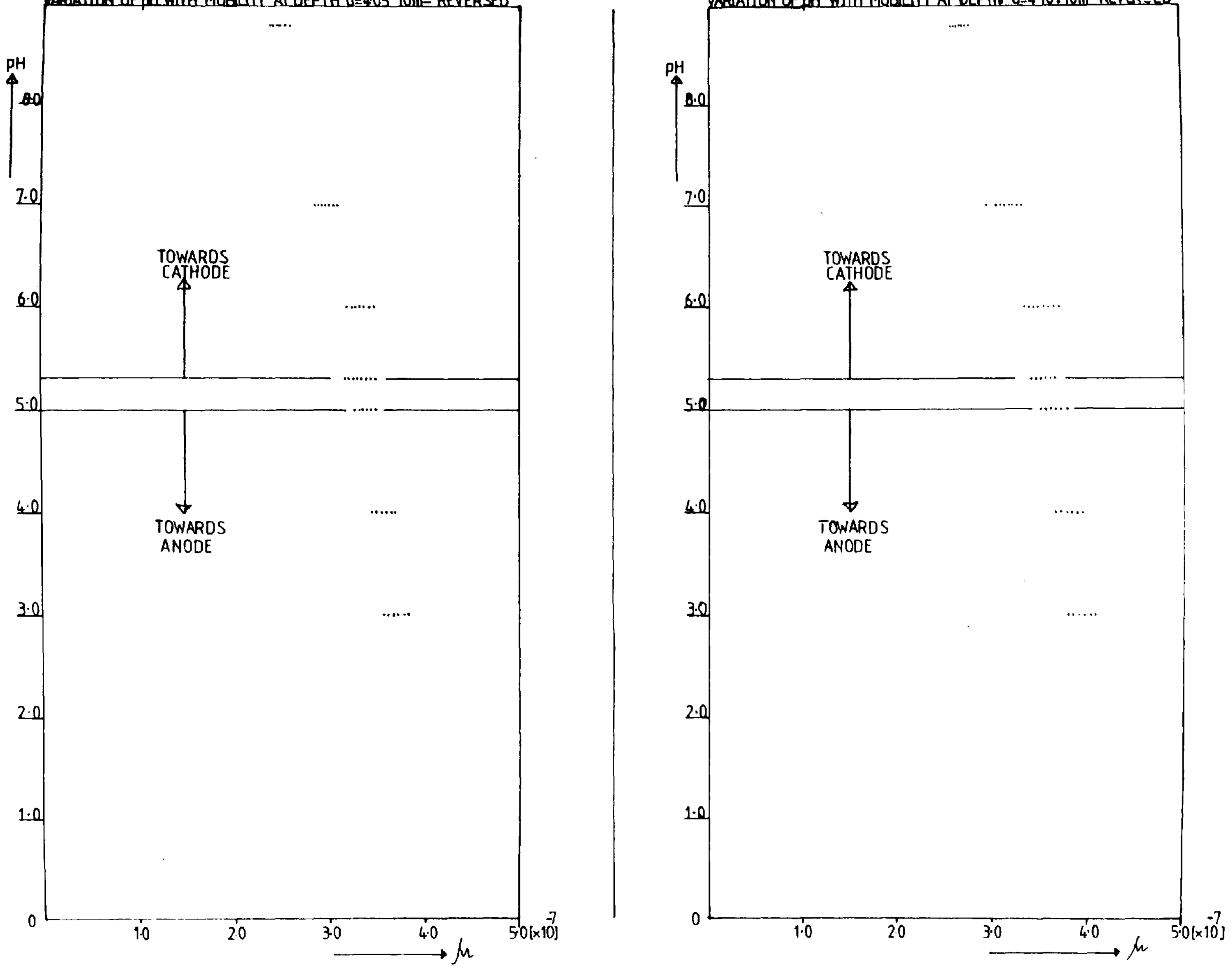
FIGURE. 7.63



VARIATION OF pH WITH MOBILITY AT DEPTH d=3·90.10^{-2}m— CIRCUIT REVERSED

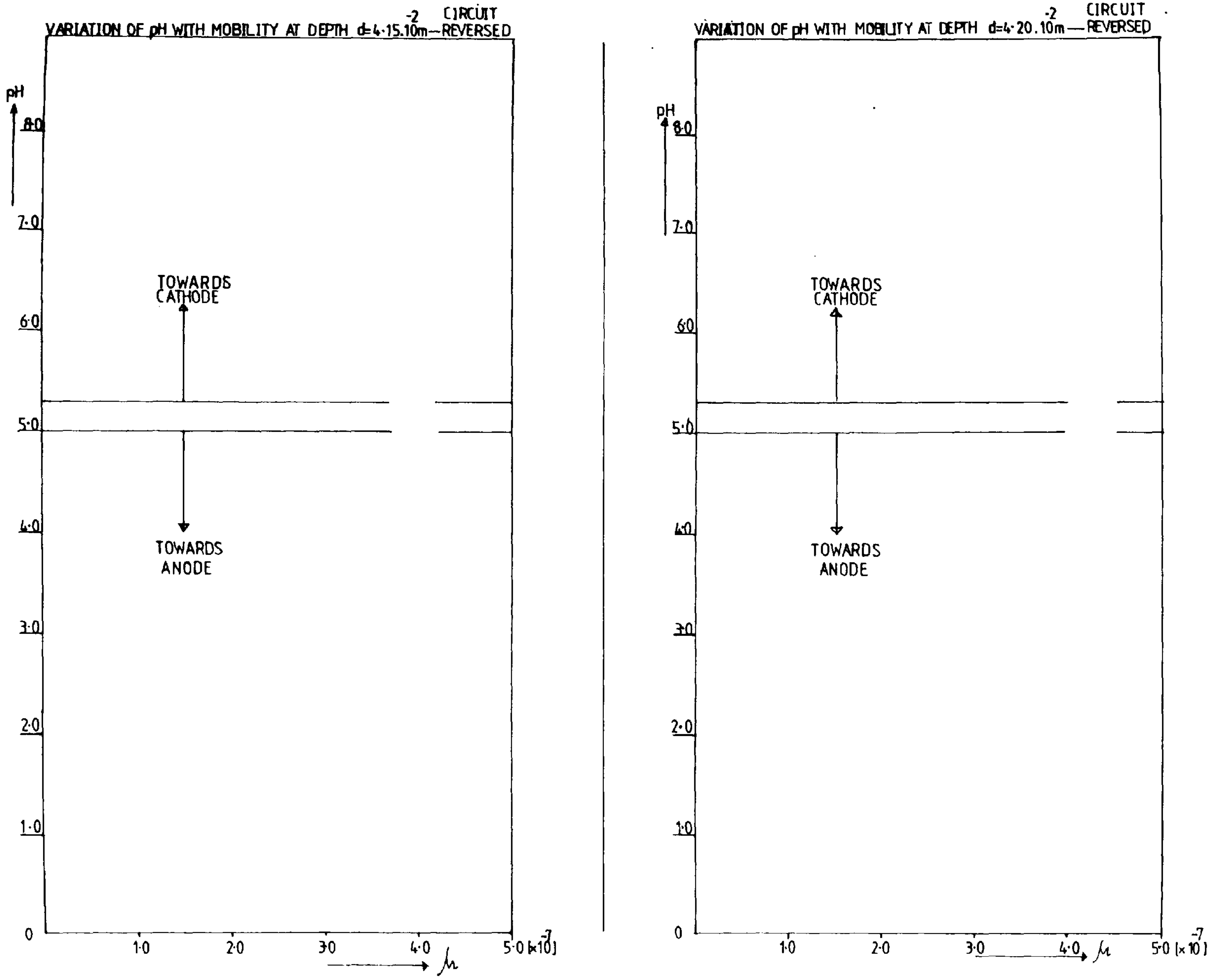
VARIATION OF pH WITH MOBILITY AT DEPTH d=3·95.10^{-2}m— CIRCUIT REVERSED

FIGURE.7.64


VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}05\ 10^{-2}m$ — CIRCUIT REVERSED

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}10 . 10^{-2}m$ — CIRCUIT REVERSED

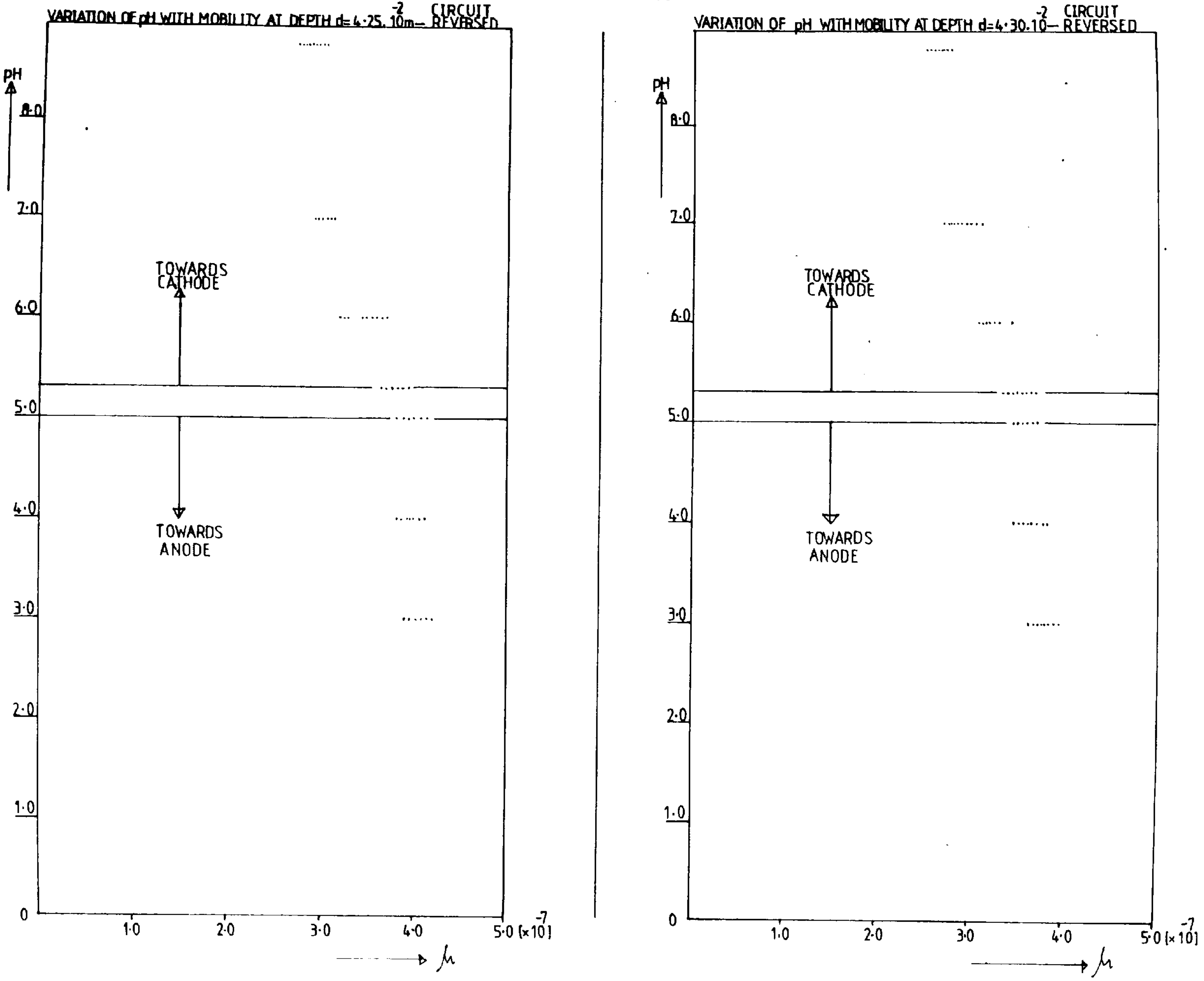
FIGURE. 7. 65



VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}15.10^{-2}$m — CIRCUIT REVERSED

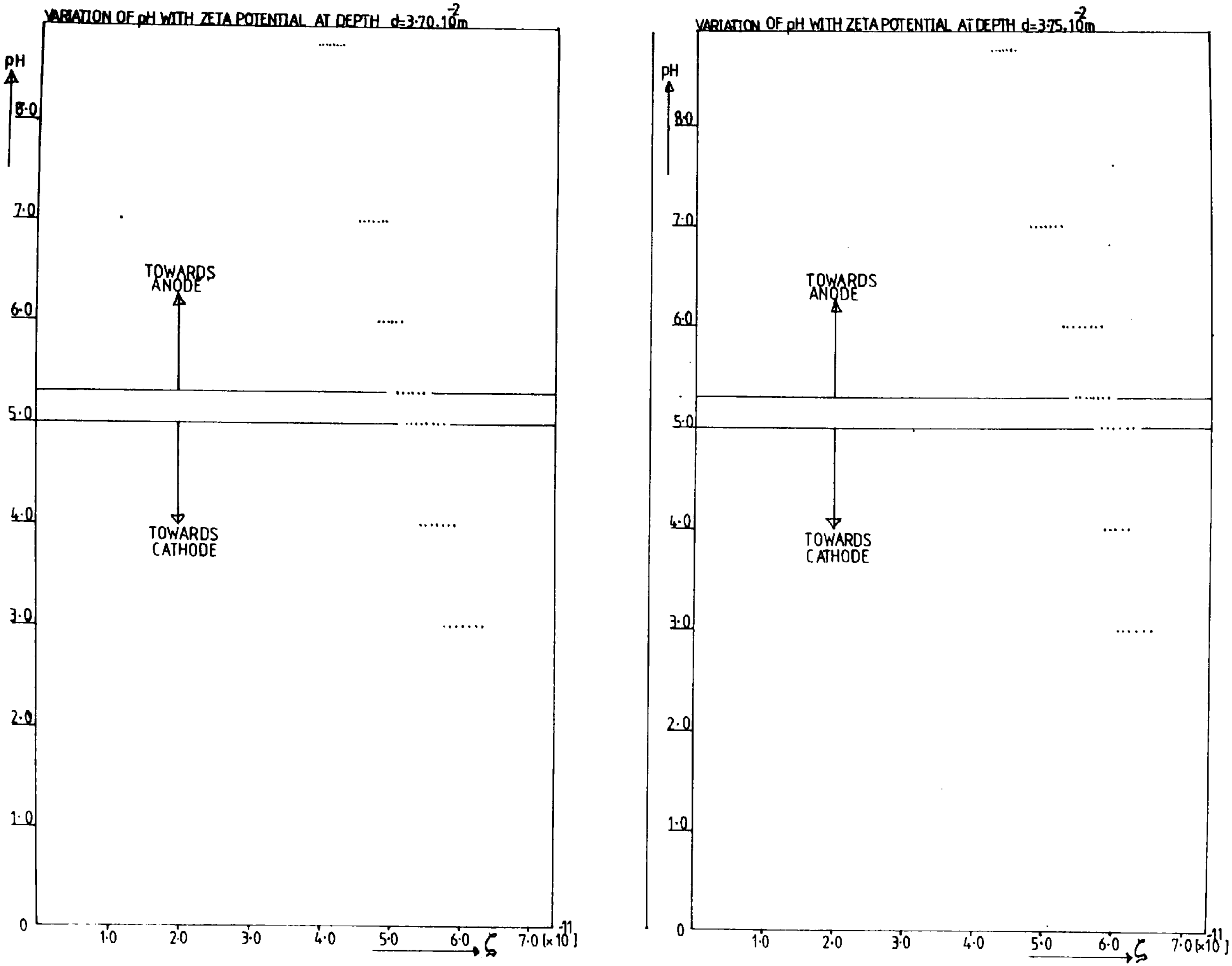
VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}20.10^{-2}$m — CIRCUIT REVERSED

FIGURE. 7.66


VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}25.10^{-2}$m— CIRCUIT REVERSED

VARIATION OF pH WITH MOBILITY AT DEPTH $d=4{\cdot}30.10^{-2}$— CIRCUIT REVERSED

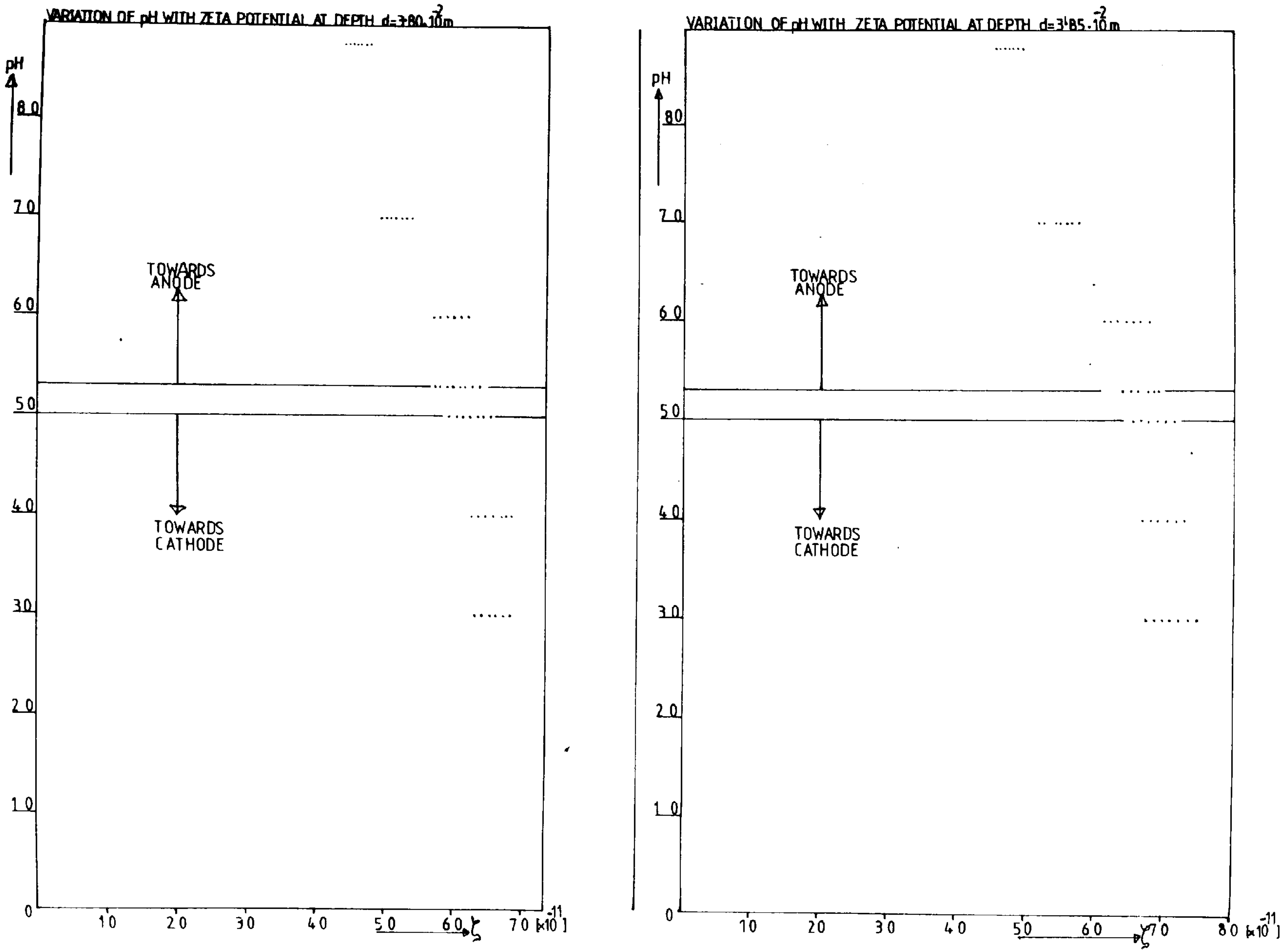
FIGURE.7.67



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}70.10^{-2}m$

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}75.10^{-2}m$

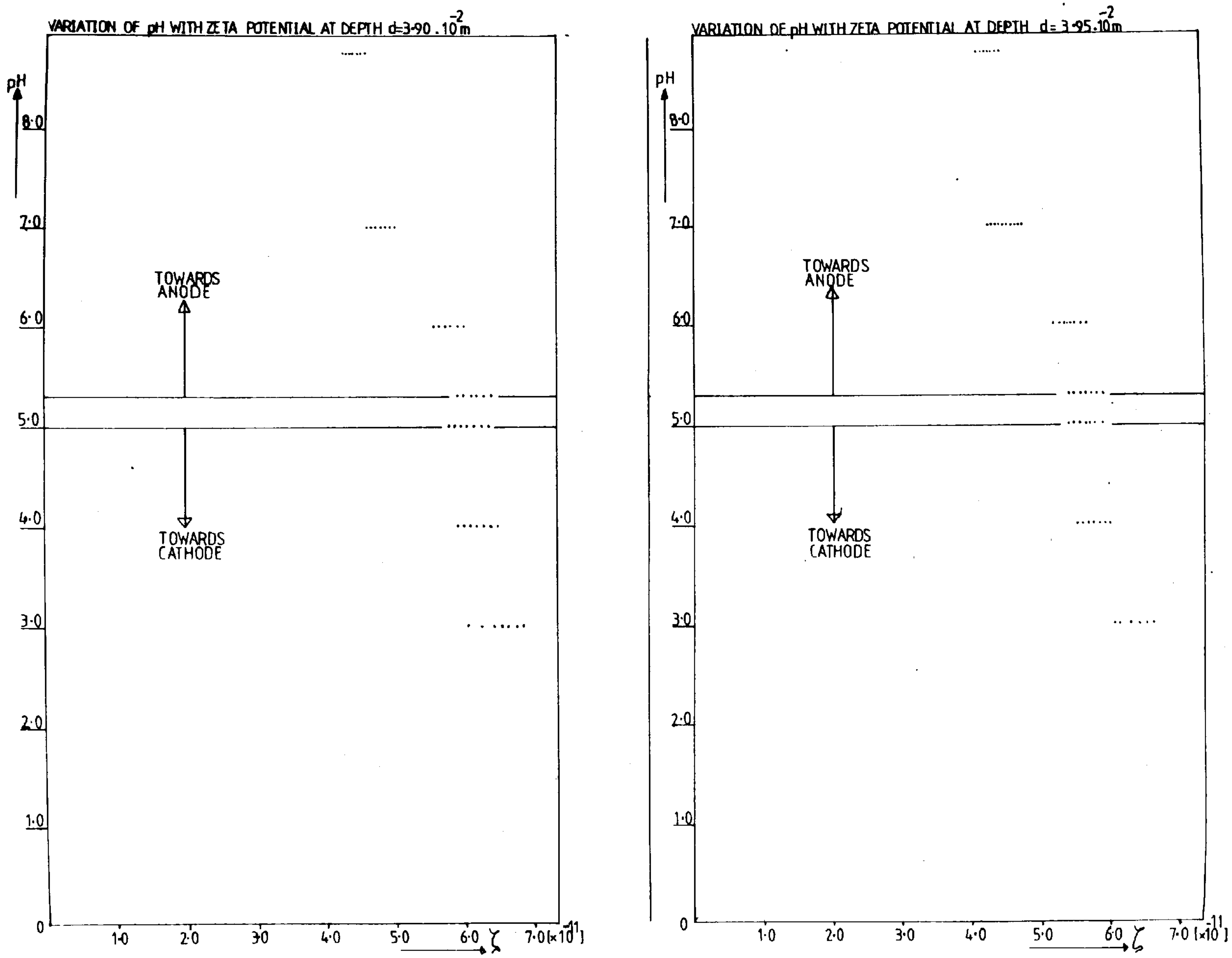
FIGURE. 7.68



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}80.10^{-2}$ m

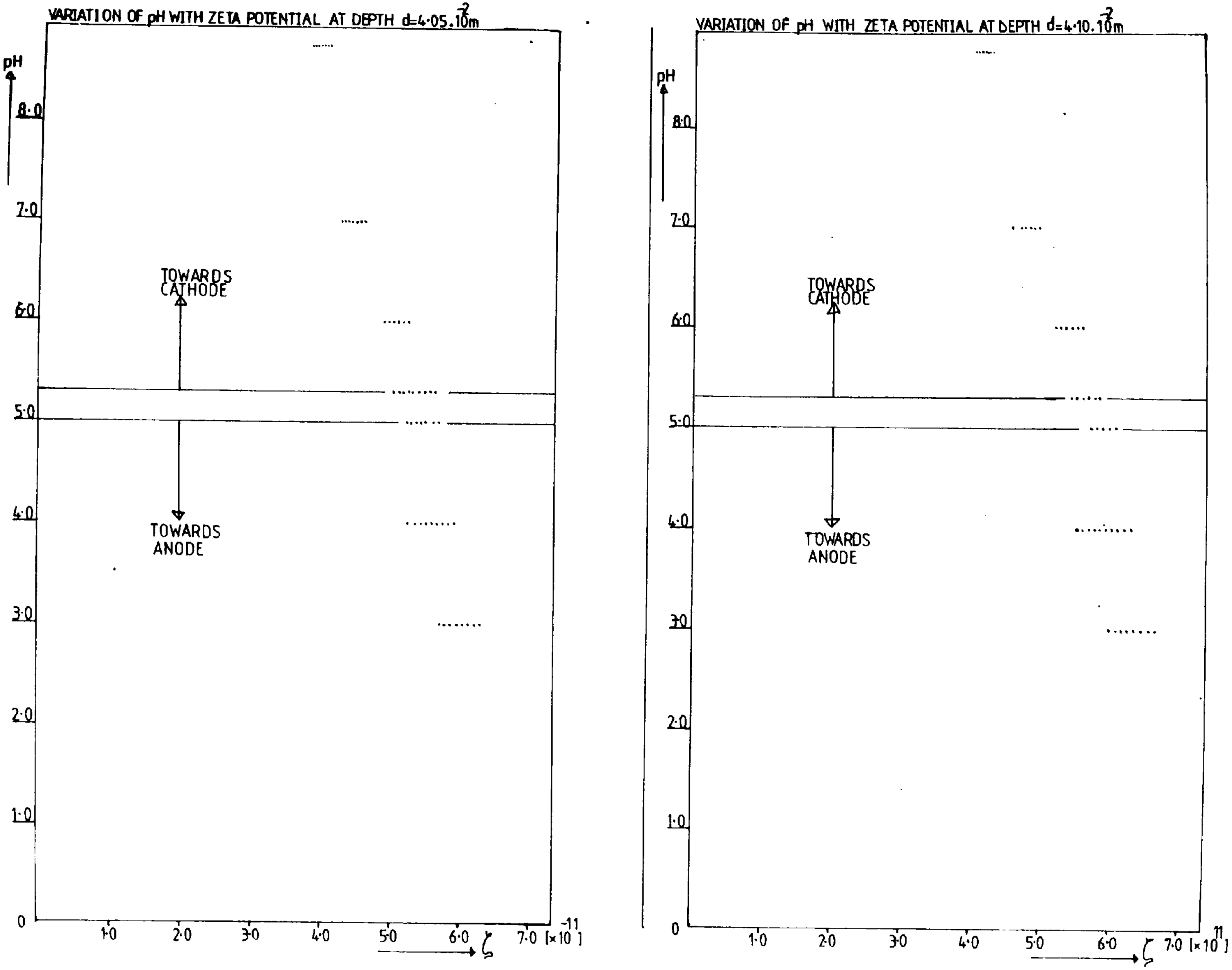
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}85.10^{-2}$ m

FIGURE.7.69


VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d = 3{\cdot}90 . 10^{-2}$ m

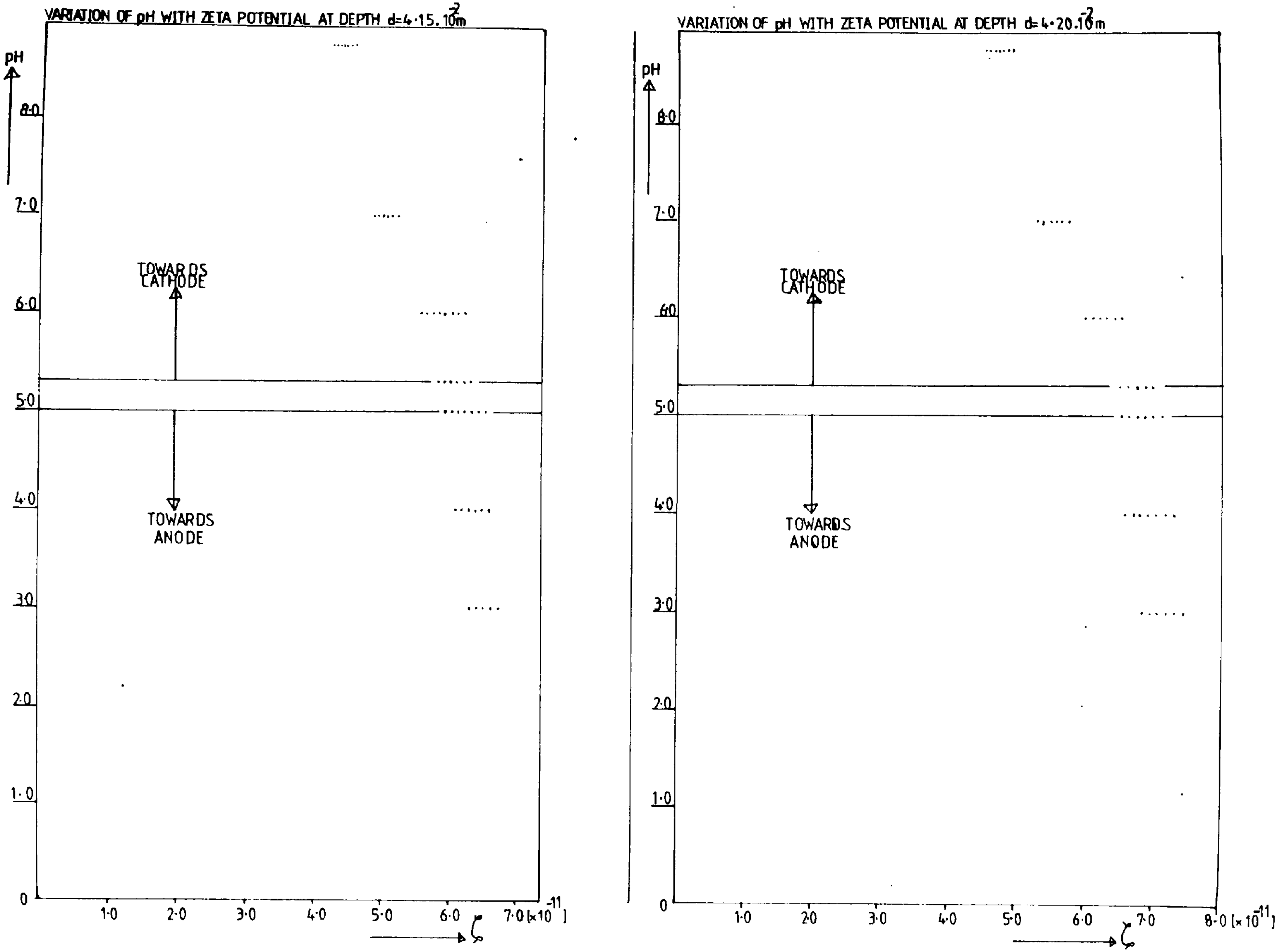
VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d = 3{\cdot}95 . 10^{-2}$ m

FIGURE. 7.70


VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}05.10^{-2}m$

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}10.10^{-2}m$

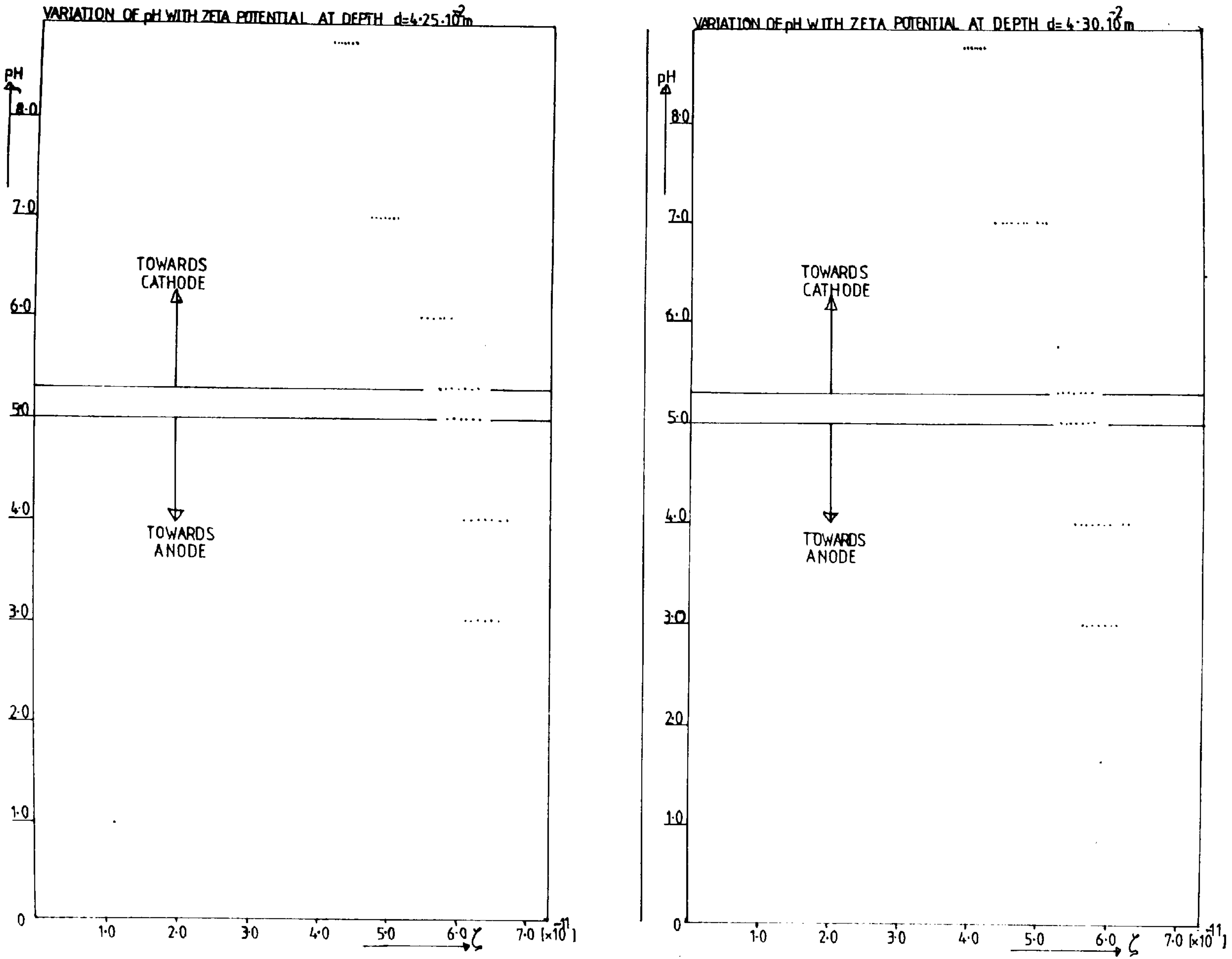
FIGURE. 7.71



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·15.10^{-2}m

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·20.10^{-2}m

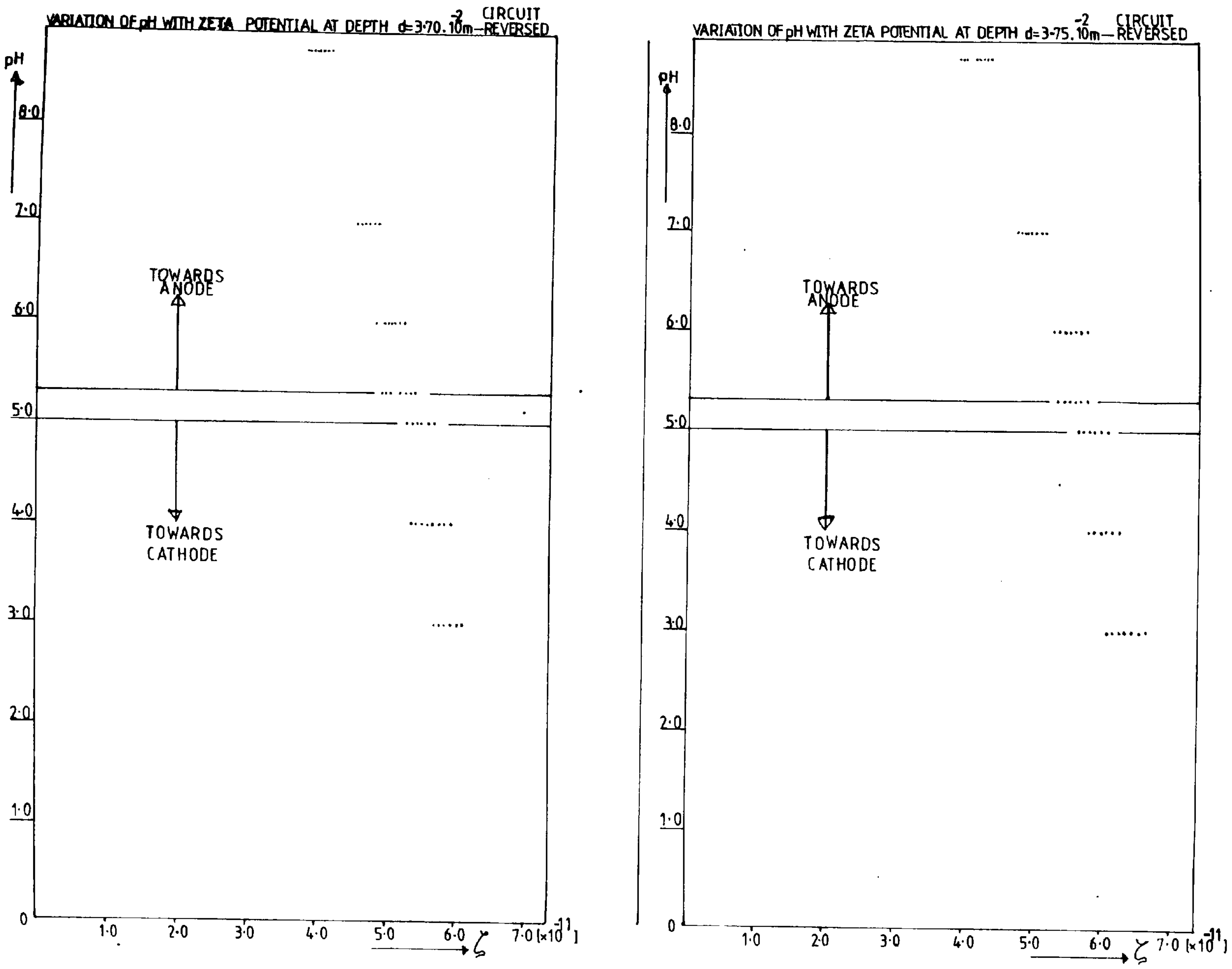
FIGURE. 7.72



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}25.10^{-2}m$

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=4{\cdot}30.10^{-2}m$

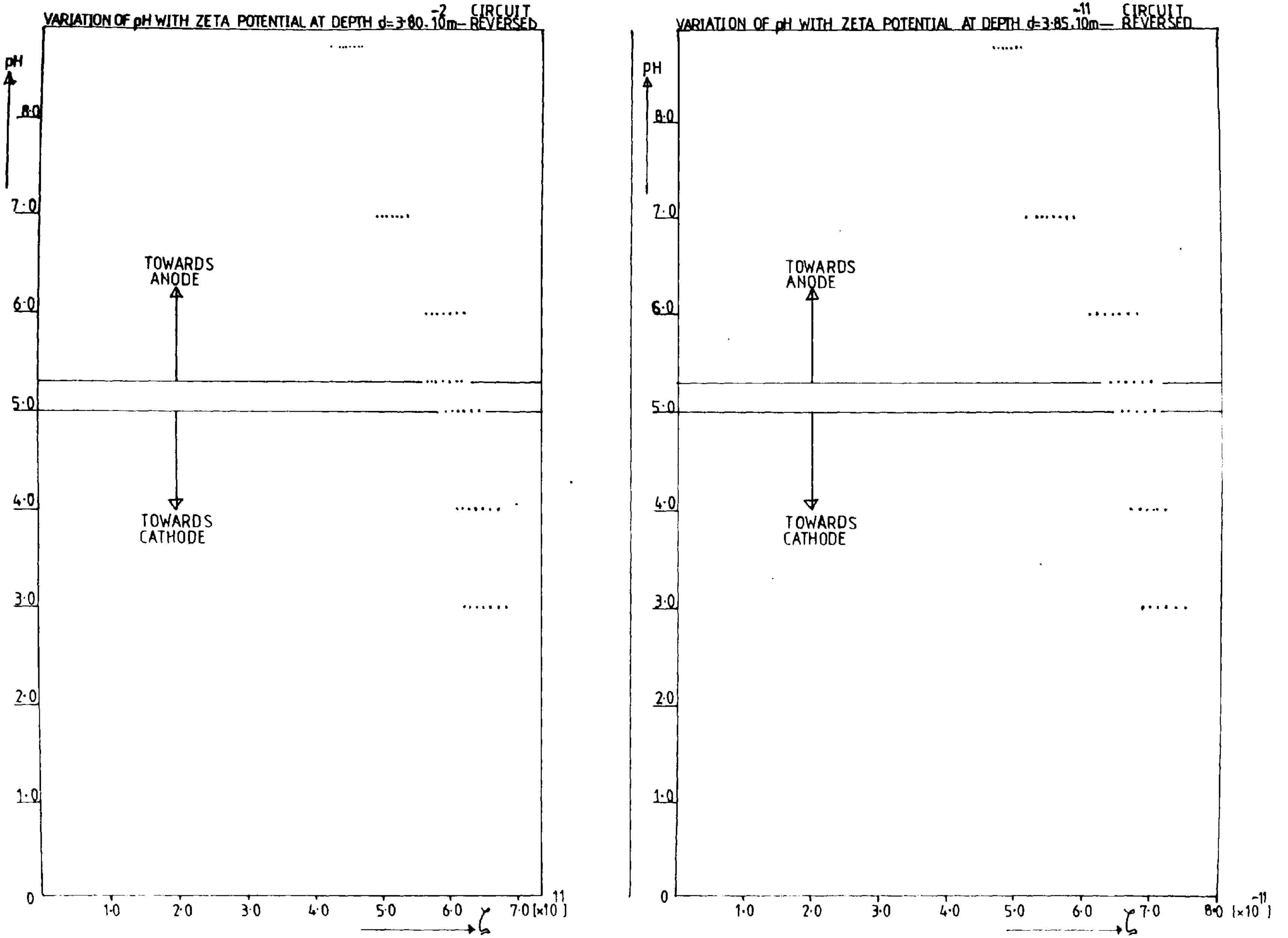
FIGURE.7.73



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}70.10^{-2}$m—CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}75.10^{-2}$m—CIRCUIT REVERSED

FIGURE. 7.74



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}80.10^{-2}$m— CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}85.10^{-11}$m— CIRCUIT REVERSED

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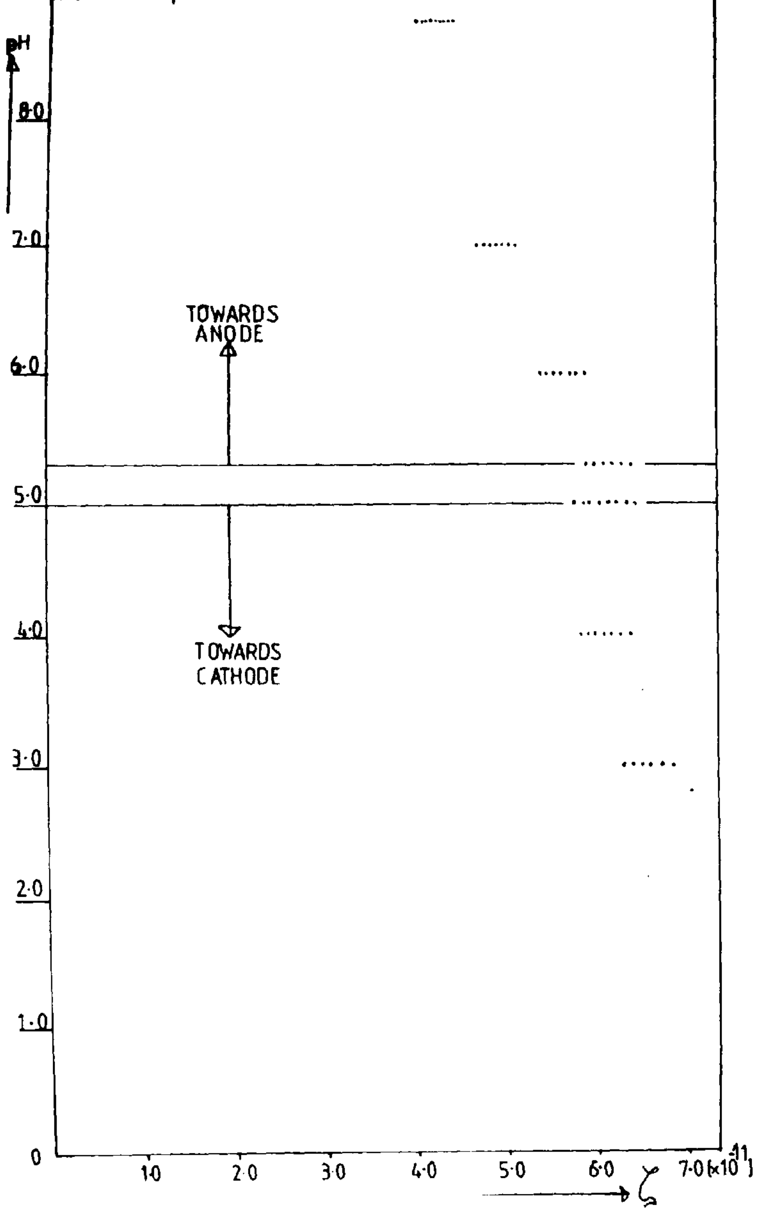
FIGURE.7.75

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}90.10^{-2}m$ — CIRCUIT REVERSED



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH $d=3{\cdot}95.10^{-2}m$ — CIRCUIT REVERSED

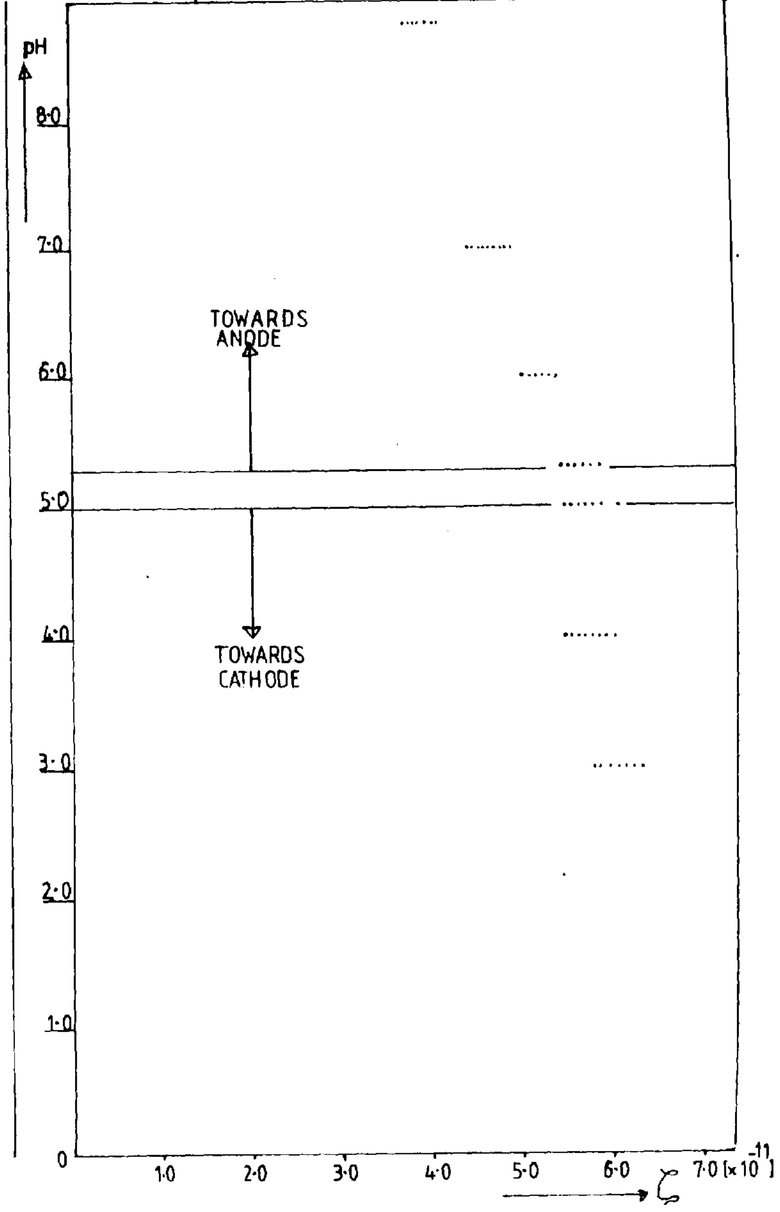
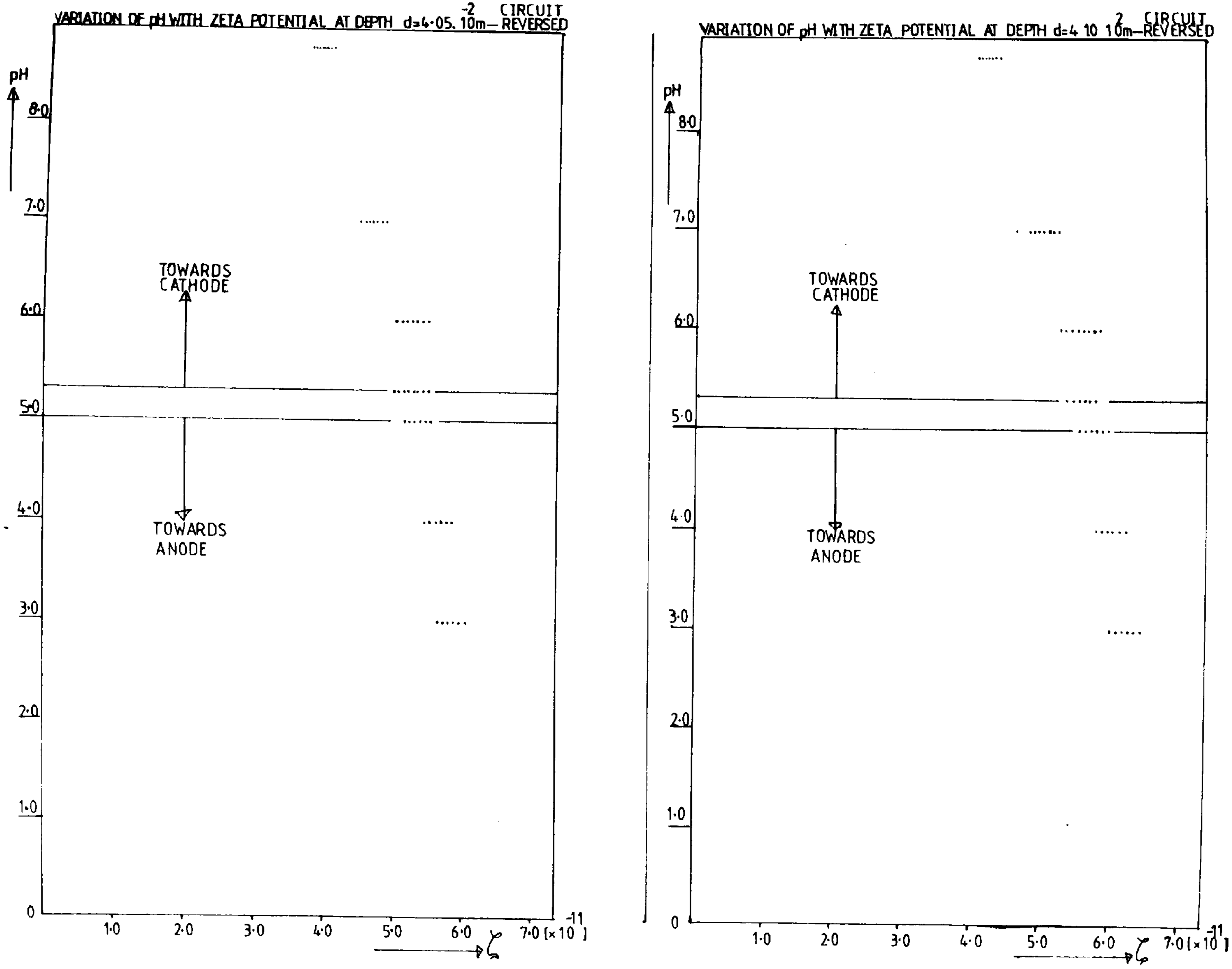


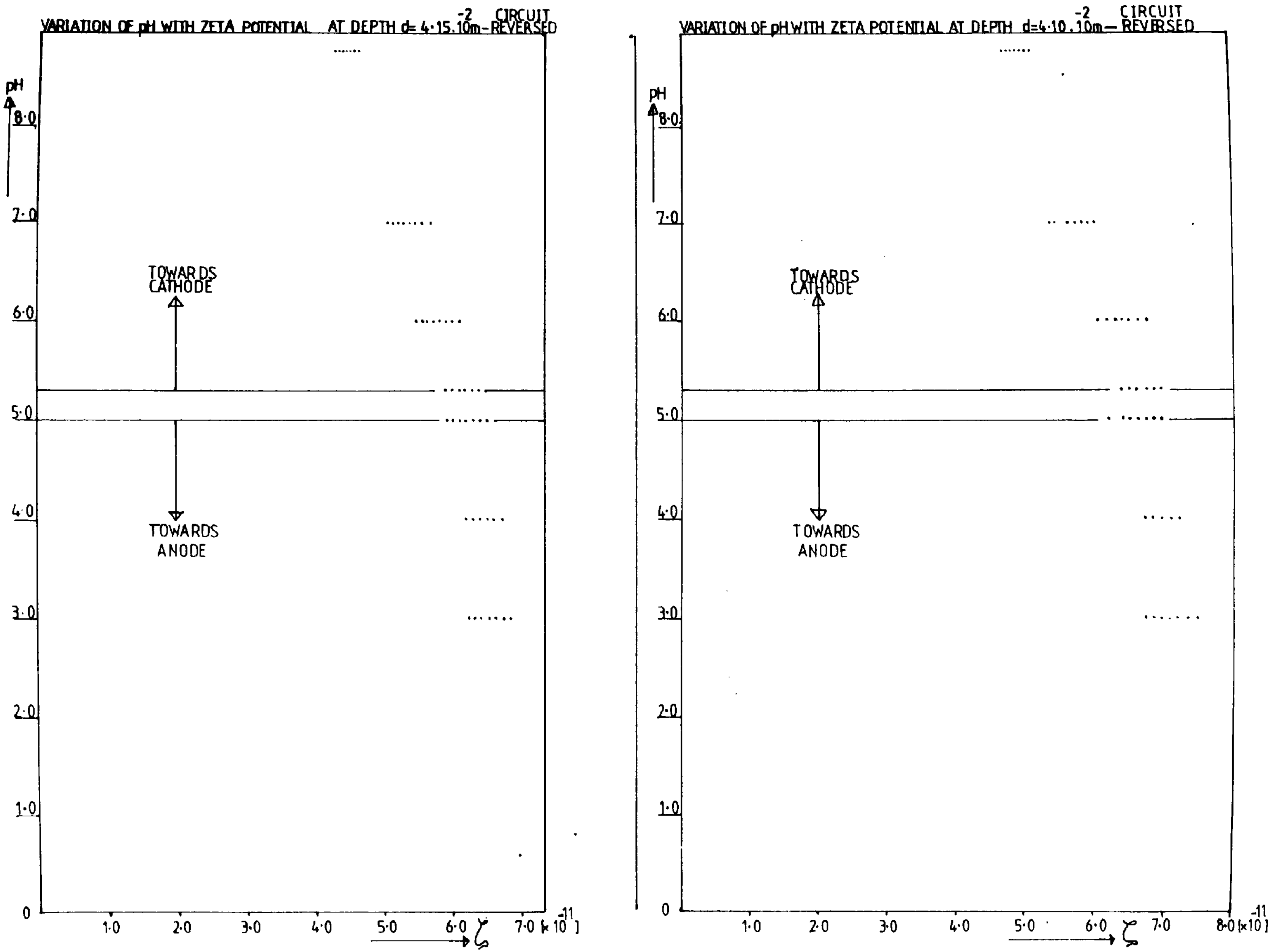
FIGURE. 7.76.



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·05.10^{-2}m— CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4 10 10^{2}m— CIRCUIT REVERSED

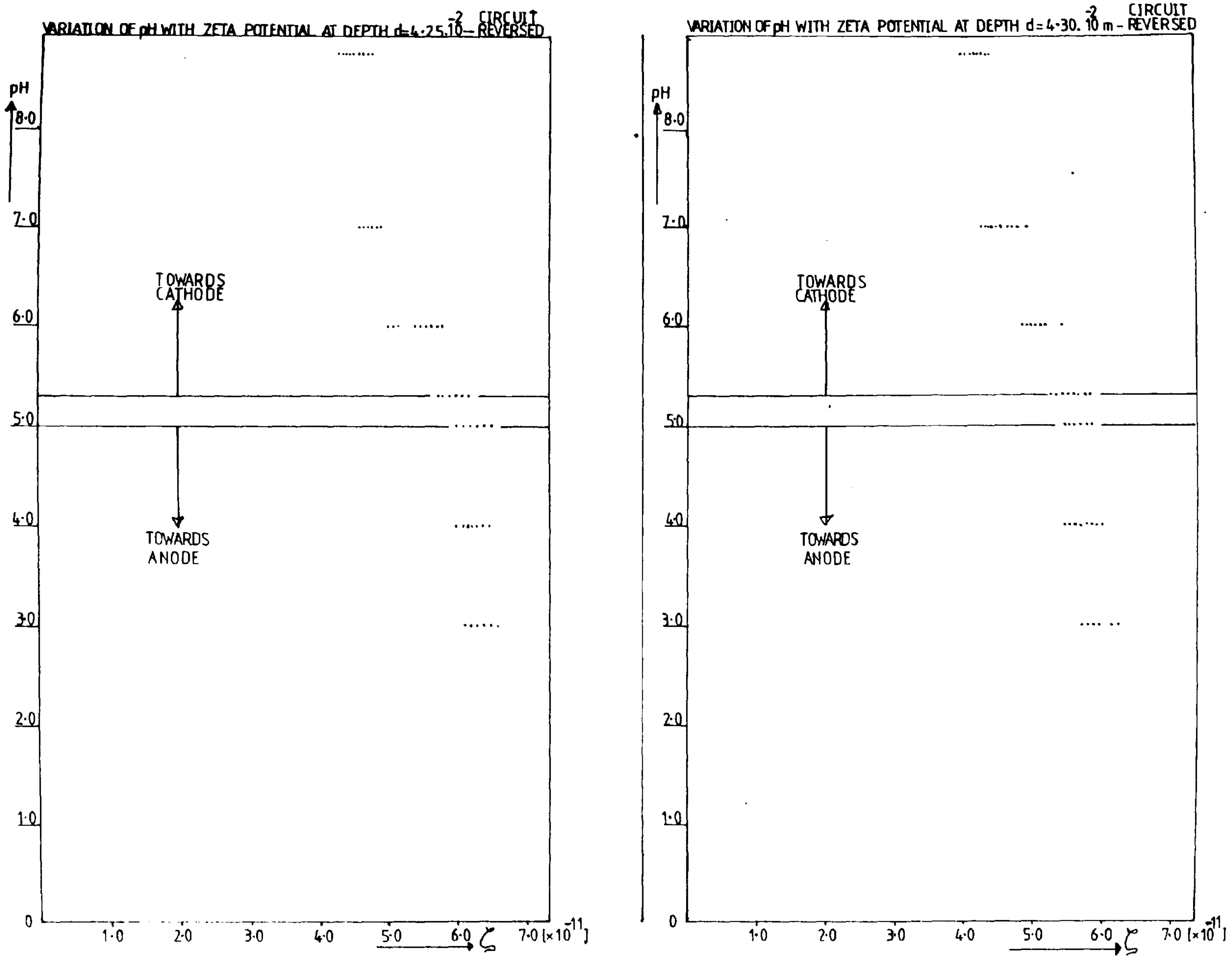
FIGURE. 7.77



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d= 4·15.10^{-2}m - CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·10.10^{-2}m — CIRCUIT REVERSED

FIGURE .7. 78



VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·25.10^{-2} – CIRCUIT REVERSED

VARIATION OF pH WITH ZETA POTENTIAL AT DEPTH d=4·30. 10^{-2} m – CIRCUIT REVERSED

7.6 FLOCCULATION OF COLLIERY WASTE-WATER - HCl and 100ppm POLYACRYLAMIDE.

1.

BEAKERS	A	B	C	D	E	F	G	H
Volume of Sample ml	200	200	200	200	200	200	200	200
pH	8.6	7.8	7.0	6.0	4.9	4.0	3.0	2.1
Amount of Flocculant ml	20	20	20	20	20	20	20	20
Optical Density	0.243	0.220	0.206	0.187	0.081	0.024	0.009	0.004

2.

BEAKERS	A	B	C	D	E	F	G	H
Volume of Sample ml	1000	1000	1000	1000	1000	1000	1000	1000
pH	8.6	7.8	7.0	6.0	4.9	4.0	3.0	2.1
Amount of Flocculant ml	100	100	100	100	100	100	100	100
Optical Density	0.251	0.226	0.211	0.182	0.072	0.021	0.012	0.007

3.

BEAKERS	A	B	C	D	E	F	G	H
Volume of Sample ml	1000	1000	1000	1000	1000	1000	1000	1000
pH	8.6	7.8	7.0	6.0	4.9	4.0	3.0	2.1
Amount of Flocculant ml	100	100	100	100	100	100	100	100
Optical Density	0.247	0.218	0.203	0.161	0.061	0.028	0.019	0.006

4. FLOCCULATION OF COLLIERY WASTE-WATER - CYANAMID SUPERFLOC 127

VOLUME OF COLLIERY WASTE-WATER = 200ml

AMOUNT OF FLOCCULANTS ADDED = 2.0ml

pH	COMMENTS
1.25	Settled quickly, leaving clear supernatant
2.10	Settled quickly, leaving clear supernatant
3.00	Settled quickly, leaving clear supernatant
4.95	Settled quickly, leaving clear supernatant
6.70	Supernatant slightly cloudy
8.55	Cloudy suspension.

FLOCCULATION OF COLLIERY WASTE-WATER

The separation of suspended solids from waste-waters for purification purposes generally involves primary treatment by gravity sedimentation, in large clarifiers. A secondary biological process and/or a tertiary physico-chemical process may follow sequentially for waste-water treatment. The physical process of sedimentation is enhanced by coagulation and flocculation initiated by chemical agents. The initially fine and colloidal particles agglomerate into larger and more dense aggregates which then settle more rapidly and more completely. Flocculation is the driving together of colloidal particles by chemical forces, hence it is the coalescing of coagulated particles into large particles.Flocculation can be of considerable benefit in improving continuous filter operations particularly when very fine size material is present. Flocculant selection is best done on an experimental basis.

The flocculation of the colliery waste-water was carried out in the laboratory by the application of subjective visual criteria to a number of test systems conducted in parallel. It was also carried out by measuring the optical densities at the various pH values.

From the determination of the optical densities after the addition of a polyacrylamide flocculant, the fines were found to settle quickly at a pH value of 4.9 or less. The clarity of the waste-water at a pH value of 4.9 or less, was seen to be much better than the original waste-water. The values of the optical densities obtained at pH value of 4.9 were determined to be 66 to 70 per cent of the original suspension, i.e. this percentage of the fines were flocculated.

Hence at a pH value of 4.9 the colliery waste-water could now be clarified by flocculation.

It should be noted that at pH values of less than 4.9, the optical densities were much lower but to obtain these pH values more acid would have to be added.

CONCLUSIONS

CHAPTER 8.

The study of the factors affecting the clarification of colliery fines was divided into two main areas. The first was concerned with the characterisation of the fines present in the suspension. These included particle size and size distribution. Chemical and mineralogical analyses were carried out by classical chemical methods and by using X-ray dispersive analysis X-ray powder crystallography was also applied to several samples and the lattice spacing (d-spacing) calculated from the Bragg equation. These results were compared with the ASTM Index and several minerals tentatively identified.

The density at ambient temperature of the raw colliery waste-water was found to vary between 972.6 kg/m^3 and 1008 kg/m^3; the density of suspension obtained after twelve hours of sedimentation between 950.1 kg/m^3 and 989.1 kg/m^3; and the density of the filtrate obtained after the filtration of any suspension varied between 940.4 kg/m^3 and 993.4 kg/m^3.

The amount of sediment obtained after twelve hours of settling the decantation of suspension above the sediment was determined to be between 3.1% and 3.6%.

The raw colliery waste-water was observed to contain fines (fine solids) of various sizes and their shapes were irregular. They were observed to be light to dark-brown and greyish-black and some of the particles were highly reflecting. In some cases, some of the light reflecting particles were enclosed in a dark brown or greyish matrix.

The Scanning electron microscope - Steroscan SEM TL 1153-OM was used to determine the shape of the particles obtained after six hours of sedimentation. Three different layers were obtained after the six hours of sedimentation namely:- the sediment; the clayey solution above the sediment and the suspension above the clayey solution.

The results indicated that the fines were of irregular shape, some plate or tube-like and of a diversity of colour and sizes.

Particle size determination was carried out using the Coulter Counter Model TA. Several fractions were examined; on a simple gravity fractionated mixture and after centrifuging and filtration through Millipore (0.22μm) filters. In general the particle size distribution was in the range of 3.5 to 92 μm for the coarsest fraction and 1.24 to 31.5 μm for the finest fraction. The results were graphed on the particle size distribution charts provided in the BS 1377:1975. From these results it was concluded that they consisted of primary clay, fine, medium and course silt and fine sand.

The elemental analysis was carried out in the first instance by the application of the Energy Dispersive X-ray Microanalysis using the equipment - Link Systems 860.

These elements were found to be present on the application of the Energy Dispersive X-ray Microanalysis procedure: Aluminium (Al), Silicon (Si), Potassium (K), Calcium (Ca), Titanium (Ti) and Iron(Fe).

The fines were dried, ashed and subjected to chemical analysis according to BS.1016. The results obtained from this elemental analysis agreed favourably with those using Energy Dispersive X-Ray Microanalysis procedure. These substances were found to be present: Silicon dioxide (SiO_2) Aluminium oxide (Al_2O_3), Sodium oxide (Na_2O), Potassium oxide (K_2O), Iron (III) oxide (Fe_2O_3), Titanium oxide (TiO_2). Manganese oxide (Mn_3O_4); Phosphorus pentoxide (P_2O_5); Calcium oxide (CaO), Magnesium oxide (MgO) and Sulphur (as Sulphur trioxide, SO_3). The preferred methods in industry and used in this investigation for the analysis of oxides of magnesium and sulphur are the atomic absorption spectrophotometry and Eschka's method respectively.

Microanalytical techniques were applied in the analysis of carbon and other elements which could not be analyzed by the Energy Dispersive X-ray equipment.

The total carbon was found to be 9.2%.

The fines were also analysed for organic matter and found to contain Carbon and Hydrogen together with the elements Nitrogen, Chlorine, Sulphur and Phosphorus.

X-ray powder crystallography was applied to the same samples used for particle size distribution (Counter-counter) and the lattice spacing calculated from the Bragg equation. These results were compared with the ASTM Index and the minerals tentatively identified are in Appendix A5.

From the Inorganic Index to the Powder Diffraction File (1969) complied by the Joint Committee on Powder Diffraction Standards, the lattice or d-spacings calculated for the reflections obtained from the X-ray analysis corresponded with those of basic aluminium silicate and aluminium silicate hydroxide. These compounds obtained from the X-ray analysis conform to the elemental analysis (chemical analysis) and also to the particle size distribution chart - BS 1377;1975 fig.10, which gives clays to be present. Clays are basically aluminium silicates.

On the application of X-ray powder crystallography the fines were analysed to contain Basic Aluminium Silicate ($Al_2Si_2O_5(OH)_4$) and Aluminium Silicate Hydrate ($Al_2Si_2O_5(OH)_4.2H_2O$). The Literature survey indicated that the clay minerals are essentially hydrous aluminium silicates with magnesium or iron substituting wholly or in part for the aluminium in some minerals and with alkaline or alkaline earth present as essential constituents in some of them. Some clays are composed of a single clay mineral, but in many there is a mixture. In addition to the clay minerals some contain varying amounts of the so-called non-clay minerals of which quartz, calcite, fedspar and pyrite are important examples. Also, many clay minerals contain organic matter and water soluble salts.

The minerals were also analysed using a differential scanning calorimeter and thermogravimetric system. The presence of the organic portion prevented any detailed interpretation of the inorganic constituents.

Two thermal peaks were obtained in each case the first occurring around 100°C and the second around 450°C to 550°C.

The first peak corresponds to the loss of water and the second is probably due to the decomposition of organic matter. The presence of the organic portion present prevented any detailed interpretation of inorganic constituents present in the colliery fines.

Hence unless the organic fraction can be physically separated from the rest, unequivocal identification of the minerals would not be possible. Consequently attempts were made to separate the coal-inorganic constituents by gravity separations and by use of heavy liquid density gradients.

There was no separation into distinct zones and bonds and it was concluded that the samples were a complete mixture of overlapping sizes and densities.

The second part of the investigation was concerned with the study of the electrokinetic parameters and flocculation characteristics.

Until recently most electrophonetic experiments have involved cumbersome equipment, tedious microscopic observation and the use of dark-field illumination.

The micro-electrophoretic apparatus which has now been designed for the measurements of electrophoretic mobility, particle charge, and zero point of charge and isoelectric point of charge combines the simplicity of construction with a greatly improved method of measurement of velocity of the particles and reduction in contamination of the cell. The images of the particles were projected onto a television screen and this eliminates the need of tedious measurement of the velocity of the particles on using a microscope graticule. It utilizes the ultra-microscope principle of direct illumination and the light source is placed directly below the electrophoretic cell.

The electrophoretic mobility of quartz, the zero point of charge and the iso-electric point were determined using the re-designed microphoretic apparatus previously described in paragraphs 4.3 and fig.9.2. The quartz particles were found to be negatively charged and this agreed with the work of Bhappu and Deju (128) and also Hunter(4). The graphs of the mobility profile at different pH values against the various levels of cell depth within the electrophoretic cell compared favourably with those obtained by Hunter(4), Shergold et al(129) and Presad(70). These graphs can be seen in Figures 7.1 to 7.6. At a particular cell depth there were obtained different electrophoretic mobilities of the particles. This could be explained by the fact that there were different particle size distributions within the quartz suspension used.

The graphs of the mobility profile at the same depth but against different pH values can be seen in Figures 7.7 to 7.13. It could be seen on these graphs that between the pH values of 5.6 and 4.0, all the quartz particles moved towards the anode; between pH 4.0 and 3.8 some moved towards the anode and some towards the cathode, and at pH values less than 3.8 the particles moved towards the cathode.

The zero charge was found to be at a pH value of 3.8 which compared favourably with previous reported values(4),(128).

The design of the apparatus allows very accurate mobility measurements and since the lens could be focussed at different depths within the cell it should enable accurate mobility measurements of mixtures of different minerals which because of density differences would settle at a different level within the cell.

The charges on the fines in the colliery waste-water were determined to be both positive and negative as can be seen in the mobility profile at the various pH values against the different levels of cell depth within the electrophoretic cell. (Figures 7.14 to 7.23).

On viewing these fines under an optical microscope these coal particles appeared to be coated, and this was further confirmed by scanning electron microscopy. They were also found to be aluminium silicates from x-ray crystallography. The coating on the coal particles were thought to be a layer of aluminium silicates which are basically colloidal clay particles, the hydrophilic nature of which is able to prevent the attachment of an air bubble to the hydrophobic coal surface.

It would seem unlikely for a clay slime which is negatively charged to coat the surface of a coal particle carrying quite a high potential of the same sign. However, van Olphen(26) observed that sub-micro-scopic particles of montmorrilonite clays exist as thin platelets and from experimental evidence he concluded that they carry a dual electrical charge. Hence the dual charge on the fines in colliery waste-water appears to be due to the imperfections in the silicate crystal lattice structure in which the flat surfaces are negatively charged whilst the exposure of alumina along the edges of the platelet is responsible for the positive charge.

It could be possible that the positively charged edges of the clay particles would be attracted by the negatively charged coal surfaces so that the clay particles would become oriented perpendicularly to the surface, and thus being more remote, the negative charges on the flat clay surfaces exercises less repulsion and equilibrium may be possible.

Several investigators(145,146,147) have indicated that positive sites exist on the edges of clay crystals owing to the exposed lattice aluminium atoms at the locations. Consequently clay particles possess two oppositely charged double layers, one associated with the face of the clay plates and the other associated with the edges of the plates.

The graphs of the mobility at different pH values on using hydrochloric acid against the various levels of cell depth compared favourably with each other with the reversal of charge occurring at pH value of 4.9.

The graphs of mobility and zeta potential profiles at the same depth but against the different pH values have been illustrated in Figures 7.24 to 7.47 using hydrochloric acid.

For pH values between 8.60 and 5.20 and between the cell depth of 3.75 to 3.95 10^{-2}m., the particles moved towards the anode and between the cell depth of 4.05 to 4.30 10^{-2}(m), the particles moved towards the cathode.

Between the pH values of 5.20 and 4.90, some particles moved towards the anode, some towards the cathode, and some in random motion and some virtually at rest (not moving in any direction). Since the movement of the particles was towards both the anode and cathode, there could be the same number of positive and negative charges and hence this could be the iso-electrical point (IEP)[4,10,14,148,149].

At pH values of 4.9 or less and between the cell depth of 3.70 to 3.95 10^{-2}m, the particles moved towards the cathode (charge reversal) and between the cell depth of 4.05 to 4.30 10^{-2}m, the particles moved towards the anode (charge reversal), hence this pH value of 4.9 is known as the zero point of charge (zpc). The existence of the zero point of charge thus explains the reversal of the charge. From these graphs the iso-electric point and the zero point of charge should coincide.

The graphs of the mobility profiles at different pH values against the various levels of depth within the electrophoretic cell using sulphuric acid compared favourably with those using hydrochloric acid. These graphs can be seen on Figures 7.48 to 7.54.

The variation of pH with electrophoretic mobility and zeta potential at the same depth in the electrophoretic cell also illustrated the same graphical shapes (see Figures 7.55 to 7.78) except that between pH values of 5.3 and 5.0, the particles moved towards both the anode and cathode whilst the others were virtually at rest or moving in all directions. Then at pH values of 5.0 or less the particles at the various depths within the electrophoretic cell moved in opposite directions (charge reversal). Hence the iso-electric point and the zero point of charge were determined to be at pH = 5.0, which agreed favourably with the results obtained on using hydrochloric acid.

The flocculation of the colliery waste-water was carried out in the laboratory by the application of subjective visual criteria to a number of test systems conducted together. It was also carried out by measuring the optical densities at the various pH values.

From the determination of the optical densities after the addition of a polyacrylamide flocculant, the fines were found to settle quickly at a pH value of 4.9 or less. The clarity of the waste-water at a pH value of 4.9 or less, was seen to be much better than the original waste-water. The values of the optical densities obtained at pH value of 4.9 were determined to be 66 to 70 per cent of the original suspension, i.e. this percentage of the fines were flocculated.

Hence at a pH value of 4.9 the colliery waste-water could now be clarified by flocculation.

It should be noted that at pH values of less than 4.9, the optical densities were much lower but to obtain these pH values more acid would have to be added.

Flocculation was then carried out by varying the pH of the colliery waste-water. It was found that the flocculation could be carried out successfully at the zero point of charge of the colliery waste-water.

Time was not available to study the optimum conditions in flocculation .However, now that the zero point of charge, iso-electric point and the nature of the charges on these fines have been studied, the quantity of the flocculant and the type of flocculants could now be studied to determine the optimum conditions for flocculation.

Handling the raw colliery waste-water should be carried out with utmost care since E.Coli was detected and it is an organism used as an indicator of faecal contamination and possible presence of pathogenic organisms.

Consequently when the current was switched on to a contaminated sample the movements of the microbes interferred with the measurements. Thus to eliminate these effects without adding reagents which might affect the mineral properties the samples showing contamination were aged until no level of microbe activity could be detected.

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APPENDIX A

PYSICO-CHEMICAL PROPERTIES OF COLLIERY WASTE-WATER

APPENDIX A1

TABLE 1.1 DENSITIES OF RAW COLLIERY WASTE-WATER, SUSPENSION AND FILTRATE.

DENSITY OF RAW COLLIERY WASTE-WATER (KG/M^3	DEVIATION	DENSITY OF SUSPENSION KG/M^3	DEVIATION	DENSITY OF FILTRATE KG/M^3	DEVIATION
983.6	7.7	979.9	24.7	985.3	24.2
980.2	11.1	989.1	33.9	980.4	19.3
979.6	11.7	985.9	30.7	993.4	32.3
972.6	18.7	983.0	27.8	959.3	1.8
990.8	0.5	744.7*		908.3	52.8
981.9	9.4	969.7	14.5	984.3	23.2
1004.0	12.7	908.3	46.9	953.7	7.4
994.5	3.2	927.0	28.2	950.4	10.7
996.1	4.8	906.4	48.8	940.4	20.7
996.9	5.6	951.2	4.0	957.5	3.6
1007.0	15.7	950.1	5.1	955.9	5.2
1008.0	16.7	952.5	2.7	954.9	6.2
MEAN = 991.3	MEAN DEVIATION = 9.8	MEAN = 955.2	MEAN DEVIATION = 24.4	MEAN = 961.1	MEAN DEVIATION = 17.3
RELATIVE MEAN DEVIATION	$= \frac{9.80}{991.3} \times 100 = 0.98\%$	RELATIVE MEAN DEVIATION	$= \frac{24.4}{955.2} \times 100 = 2.55\%$	RELATIVE MEAN DEVIATION	$= \frac{17.3}{961.1} \times 100 = 1.80\%$

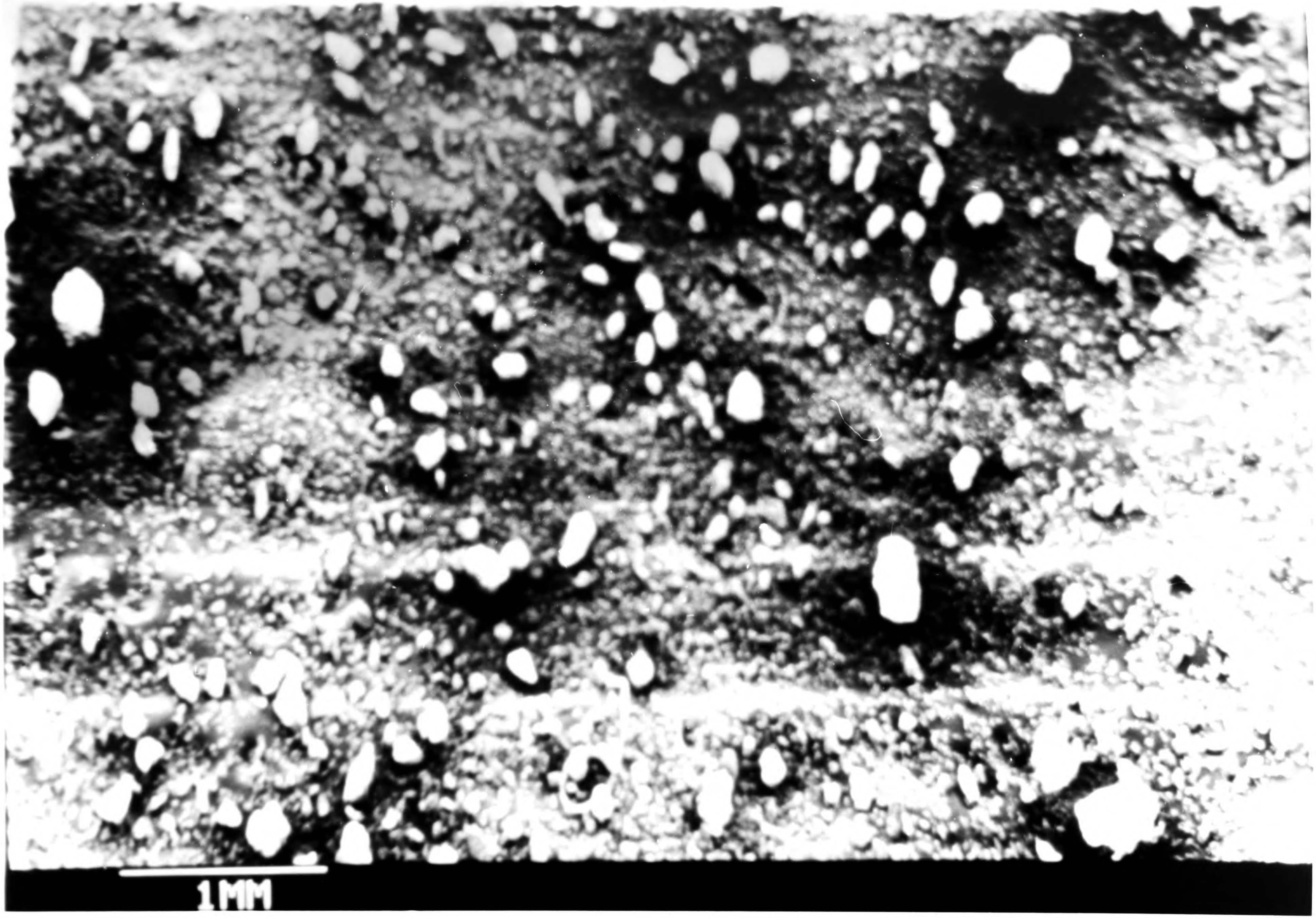
* LEFT OUT.

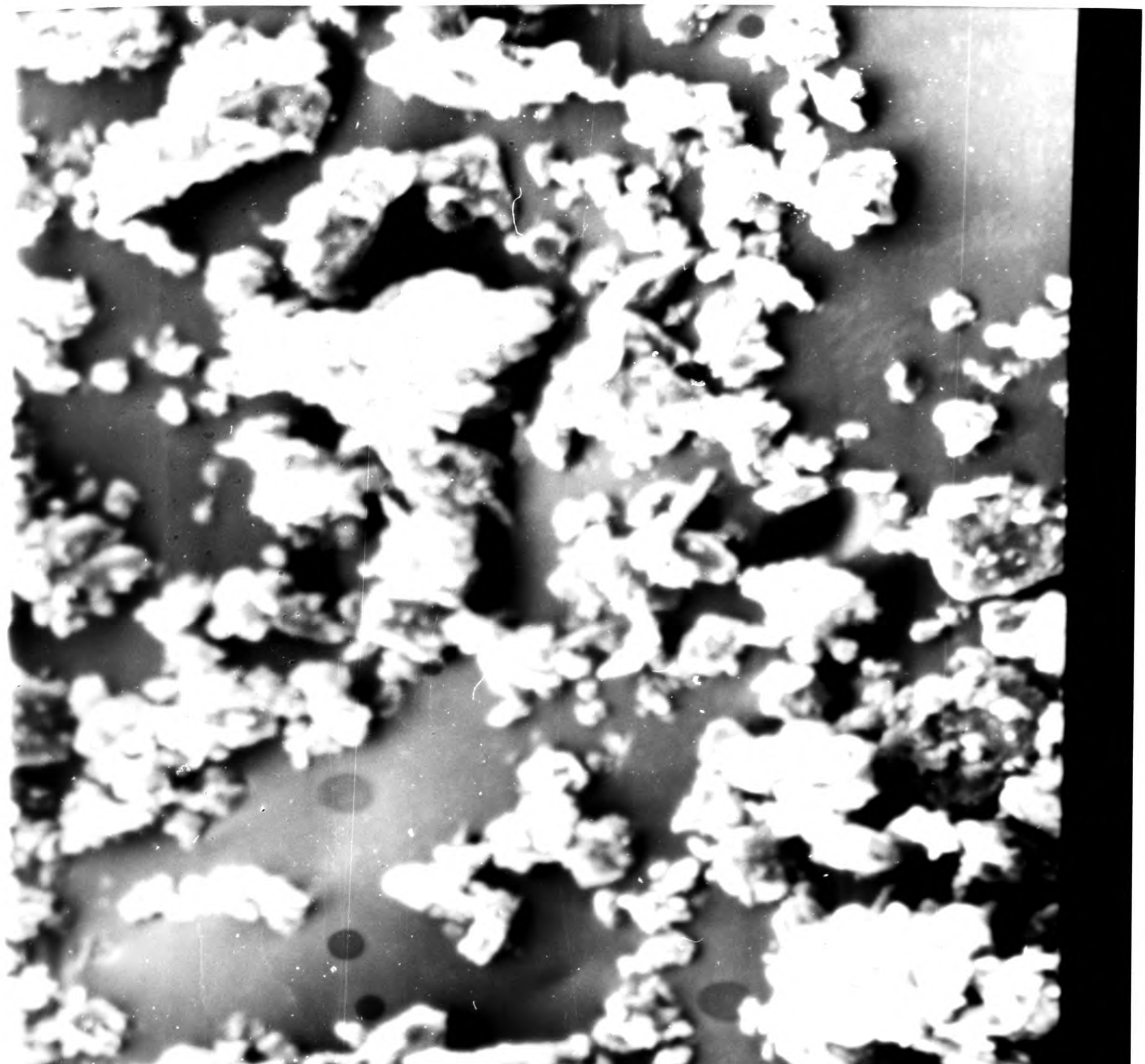
TABLE 1.2 PERCENTATES OF SOLID FINES IN THE SEDIMENT, CLAYEY SOLUTION, AND SUSPENSION

AMOUNT OF RAW COLLIERY WASTE-WATER (kg) ($\times 10^{-3}$)	AMOUNT OF SEDIMENT AFTER SEDIMENTATION (kg) ($\times 10^{-3}$)	AMOUNT OF SOLID FINES IN THE CLAYEY SUSPENSION (kg) ($\times 10^{-3}$)	AMOUNT OF SOLID FINES IN SUSPENSION (kg) (10^{-3})	PERCENTAGE OF SEDIMENT IN COLLIERY WASTE-WATER (%)	PERCENTAGE OF SOLIDS IN CLAYEY SUSPENSION IN COLLIERY WASTE-WATER (%)	PERCENTAGE OF SOLID FINES IN SUSPENSION IN COLLIERY WASTE-WATER (%)
791.91	26.15	0.6295	0.1739	3.30	0.0795	0.0220
804.19	26.13	0.6325	0.1719	3.25	0.0787	0.0215
799.71	27.79	0.6253	0.1718	3.47	0.0782	0.0215
805.92	26.42	0.7810	0.2013	3.28	0.0969	0.0249
812.83	26.18	0.6071	0.1868	3.22	0.0749	0.0230
801.54	28.82	0.6309	0.1705	3.60	0.0787	0.0213
803.21	25.46	0.6509	0.1731	3.17	0.8104	0.0216
795.63	24.98	0.6355	0.1655	3.14	0.0799	0.0208
796.87	24.82	0.6669	0.1755	3.11	0.0837	0.0220
794.48	25.02	0.5674	0.1640	3.15	0.0714	0.0206
805.88	25.64	0.6580	0.1838	3.18	0.0816	0.0228
800.67	25.97	0.6515	0.1830	3.24	0.0814	0.0229

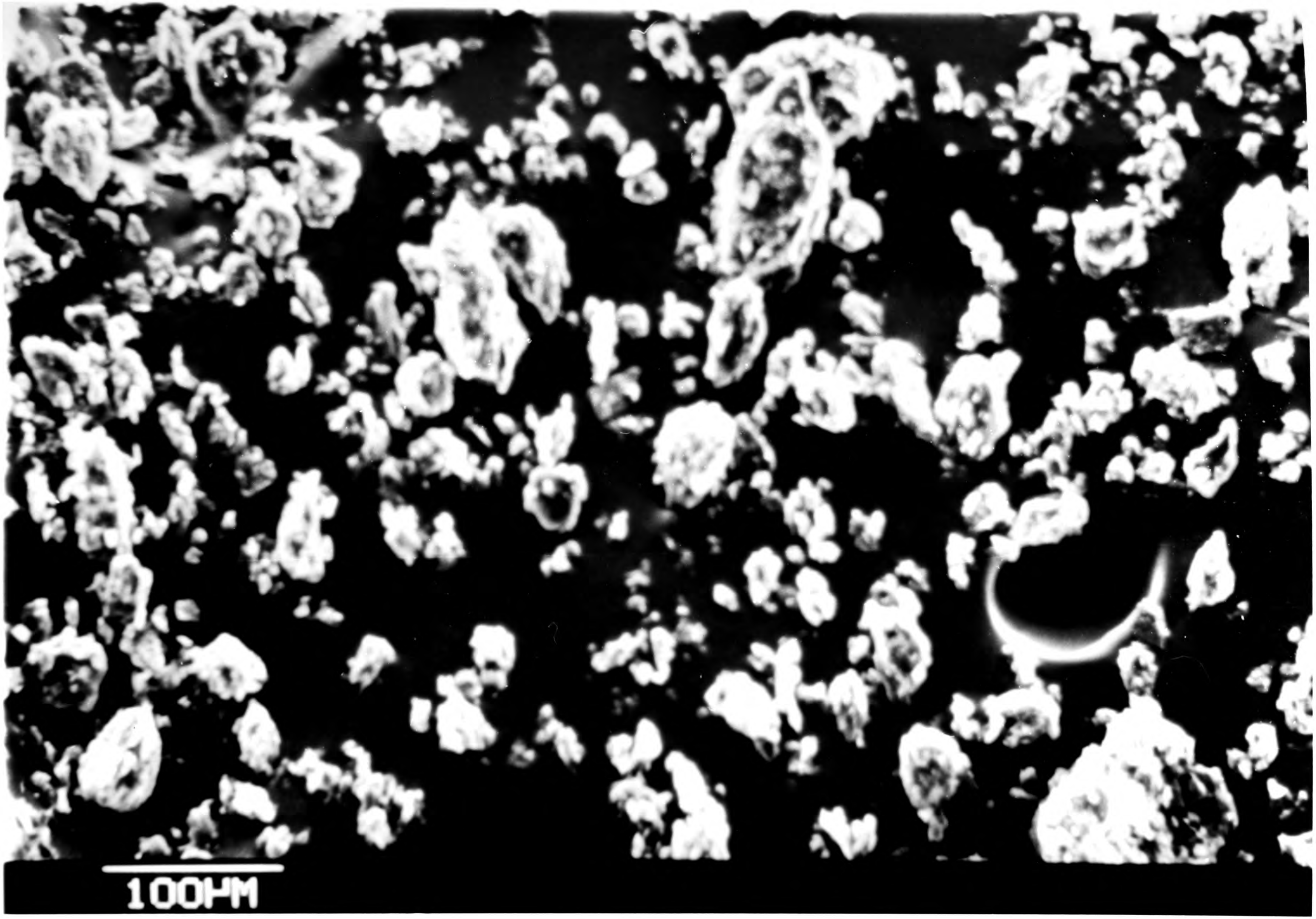
APPENDIX A2

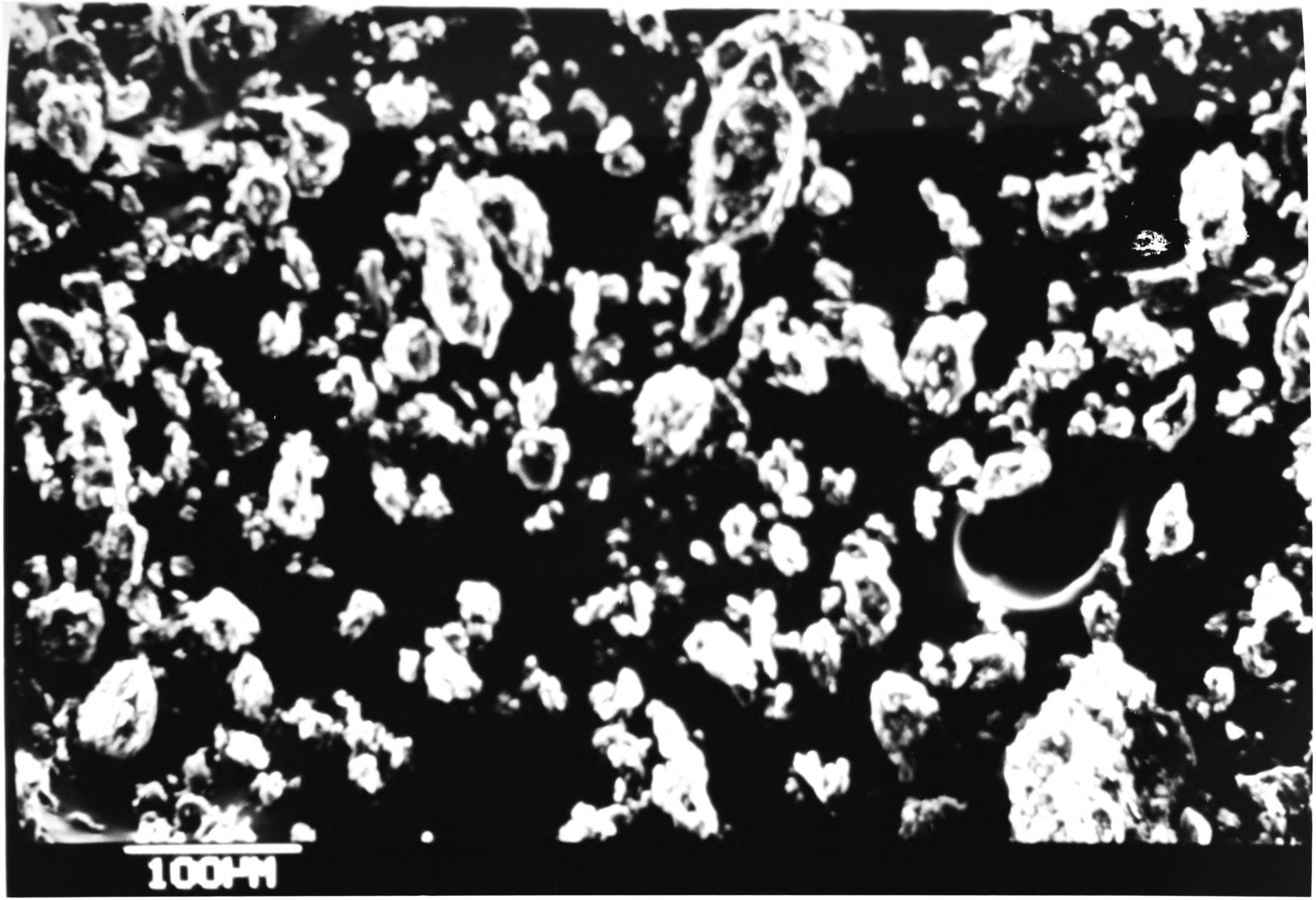
PHOTOGRAPHS OBTAINED BY THE APPLICATION OF SCANNING ELECTRON MICROSCOPY (S.E.M.)

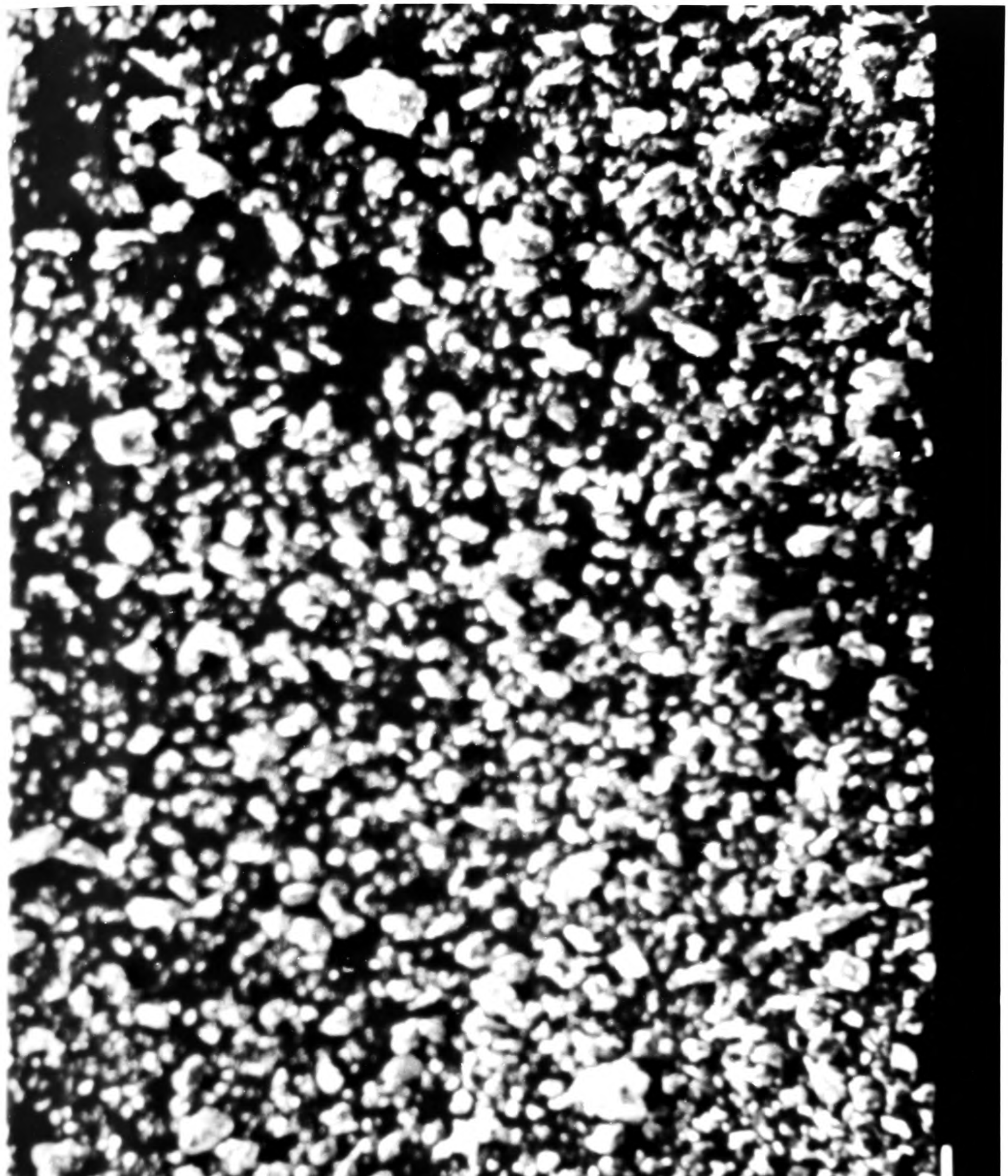

1MM

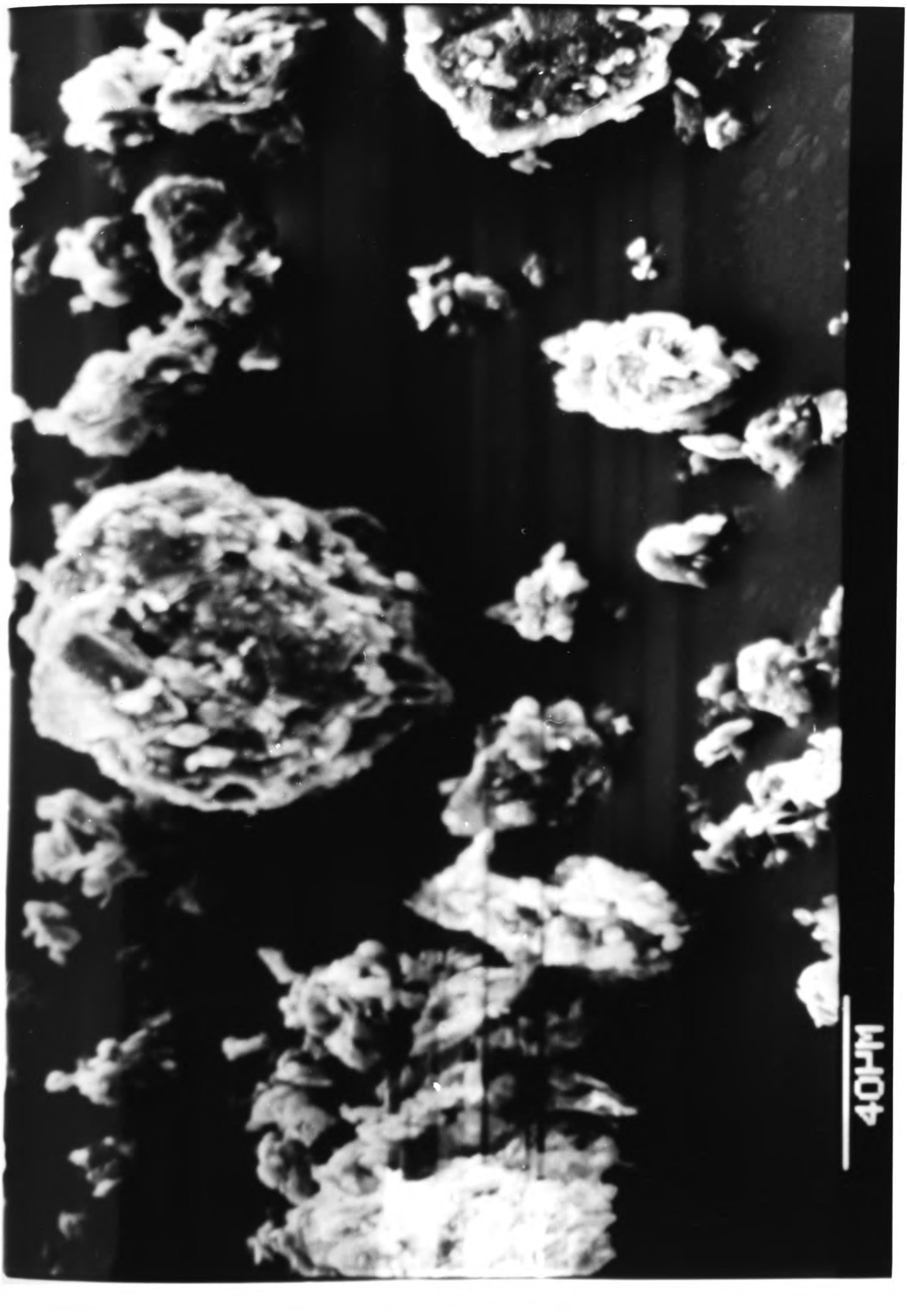


100μm


100μm


100μm


400μ


40HM

APPENDIX A3

RESULTS OBTAINED USING THE COULTER COUNTER EQUIPMENT MODEL TA.

TABLE 3.1 - SAMPLE A (1)

PARTICLE SIZE RANGE - MICRONS (μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 3.55	0.80	100.00
3.55 - 4.52	5.60	99.20
4.52 - 5.64	4.00	93.60
5.64 - 7.18	6.00	89.90
7.18 - 9.00	5.50	83.60
9.00 - 11.20	5.90	78.10
11.20 - 14.20	6.20	72.20
14.20 - 18.00	8.00	66.00
18.00 - 22.50	9.00	58.00
22.50 - 28.50	11.80	49.00
28.50 - 36.00	11.70	37.20
36.00 - 45.50	10.50	25.50
45.50 - 57.50	8.00	15.00
57.50 - 72.00	4.40	7.00
72.00 - 91.00	2.60	2.60

Samples A(1) and A(2)

This is the particle size distribution for the particles which formed the sediment obtained from gravity settling.

TABLE 3.2 - SAMPLE A (2)

PARTICLE SIZE RANGE -MICRONS- (µm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE DISTRIBUTION
less than 3.60	0.20	100.00
3.60 - 4.60	5.80	99.80
4.60 - 5.75	3.80	94.00
5.75 - 7.30	6.00	90.20
7.30 - 9.10	5.30	84.20
9.10 - 11.50	5.80	78,60
11.50 - 14.50	6.30	72.80
14.50 - 18.30	8.30	66.50
18.30 - 22.80	8.90	58.20
22.80 - 29.00	11.90	49.30
29.00 - 36.50	11.90	37.40
36.50 - 45.60	10.50	25.00
45.60 - 58.00	8.00	15.00
58.00 - 73.00	4.40	7.00
73.00 - 91.00	2.60	2.60

TABLE 3.3 - SAMPLE B(1)

PARTICLE SIZE RANGE -MICRONS- (μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 3.65	0.20	100.00
3.65 - 4.60	10.10	99.80
4.60 - 5.80	8.20	89.70
5.80 - 7.30	12.50	81.50
7.30 - 9.20	11.20	69.00
9.20 - 11.60	10.10	57.80
11.60 - 14.60	9.10	47.70
14.60 - 18.50	9.60	38.60
18.50 - 23.40	9.00	29.00
23.40 - 29.00	7.20	20.00
29.00 - 36.50	6.00	12.80
36.50 - 45.50	3.80	6.80
45.50 - 57.80	1.40	3.00
57.80 - 73.00	0.60	1.40
73.00 - 91.00	0.80	0.80

Samples B(1) and B(2)

This is the particle size distribution for the particles which formed the clayey solution just above the sediment obtained from the gravity sedimentation.

TABLE 3.4 - SAMPLE B (2)

PARTICLE SIZE RANGE -MICRONS-(μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 3.60	0.10	100.00
3.60 - 4.55	10.30	99.90
4.55 - 5.75	8.10	89.60
5.75 - 7.25	12.50	81.50
7.25 - 9.10	11.40	69.00
9.10 - 11.50	10.10	57.60
11.50 - 14.50	9.00	47.50
14.50 - 18.20	9.60	38.50
18.20 - 22.50	9.10	28.90
22.50 - 28.50	7.30	19.80
28.50 - 36.00	6.00	12.50
36.00 - 45.50	3.70	6.50
45.50 - 57.00	1.80	2.80
57.00 - 73.00	0.50	1.00
73.00 - 91.00	0.50	0.50

TABLE 3.5 - SAMPLE C(1)

PARTICLE SIZE RANGE -MICRONS- (μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 1.24	0.50	100.00
1.24 - 1.55	14.00	99.50
1.55 - 1.95	11.00	85.00
1.95 - 2.45	16.00	74.50
2.45 - 3.10	13.00	58.50
3.10 - 3.90	10.00	45.50
3.90 - 4.95	7.50	35.50
4.95 - 6.20	5.00	28.00
6.20 - 7.90	4.50	23.00
7.90 - 9.80	3.50	18.50
9.80 - 12.40	3.00	15.00
12.40 - 15.60	2.00	12.00
15.60 - 19.60	1.50	10.00
19.60 - 24.50	3.00	8.50
24.50 - 31.50	5.50	5.50

Samples C(1) and C(2)

This is the particle size distribution for the fines in suspension after the sedimentation process and this was obtained by vacuum filtration using Millipore filters (size 0.22 um).

TABLE 3.6 - SAMPLE C (2)

PARTICLE SIZE RANGE -MICRONS- (μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 1.25	0.50	100.00
1.25 - 1.57	14.00	99.50
1.57 - 1.98	11.00	85.50
1.98 - 2.50	16.00	74.50
2.50 - 3.10	13.00	58.50
3.10 - 3.95	10.00	45.50
3.95 - 5.00	7.50	35.50
5.00 - 6.25	5.00	28.00
6.25 - 7.90	4.50	23.00
7.90 - 10.00	3.50	18.50
10.00 - 12.50	2.70	15.00
12.50 - 15.80	2.30	12.30
15.80 - 19.80	1.50	10.00
19.80 - 25.00	3.00	8.50
25.00 - 31.50	5.50	5.50

TABLE 3.7 - SAMPLE D (1)

PARTICLE SIZE RANGE -MICRON- (μm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 1.24	0.20	100.00
1.24 - 1.55	4.30	99.80
1.55 - 1.95	3.50	95.50
1.95 - 2.45	7.50	92.00
2.45 - 3.10	7.70	84.50
3.10 - 3.90	8.60	76.80
3.90 - 4.95	7.20	68.20
4.95 - 6.20	8.80	61.00
6.20 - 7.80	8.70	52.20
7.80 - 10.00	9.00	43.50
10.00 - 12.50	8.30	34.50
12.50 - 15.50	6.20	26.20
15.50 - 19.50	8.20	20.00
19.50 - 25.00	7.30	11.80
25.00 - 31.50	4.50	4.50

Samples D(1) and D(2)

This is the particle size distribution for the fines in suspension after the sedimentation process and this was obtained by centrifugation using Heraeus Christ GMBH Osterode/Harz Piccolo Centrifuge No. 38836.

TABLE 3.8 - SAMPLE D (2)

PARTICLE SIZE RANGE -MICRONS- (µm)	PERCENTAGE FREQUENCY DISTRIBUTION	CUMULATIVE PERCENTAGE FREQUENCY
less than 1.24	0.10	100.00
1.24 - 1.55	4.40	99.90
1.55 - 1.95	3.50	95.50
1.95 - 2.50	7.80	92.00
2.50 - 3.10	7.70	84.20
3.10 - 3.90	8.50	76.50
3.90 - 4.90	8.00	68.00
4.90 - 6.30	8.50	60.00
6.30 - 7.80	8.50	51.50
7.80 - 9.80	9.00	43.00
9.80 - 12.50	8.20	34.00
12.50 - 15.50	6.20	25.80
15.50 - 19.50	8.00	19.60
19.50 - 24 50	7.20	11.60
24.50 - 31.00	4.40	4.40

APPENDIX A4

RESULTS OF THE CHEMICAL ANALYSIS OF THE COLLIERY WASTE-WATER

TABLE 4.1 ENERGY DISPERSIVE X-RAY ANALYZER
LINK SYSTEMS 860

SAMPLES	ELEMENTS					
A	Al	Si	K	Ca	Ti	Fe
B	Al	Si	K	Ca	Ti	Fe
C	Al	Si	K	Ca	Ti	Fe
D	Al	Si	K	Ca	Ti	Fe

TABLE 4.1 B.S. 1016 (75.8% ASH) RAW MATERIAL EVAPORATED AT 50°C FOLLOWED BY DRYING IN VACUUM AT 50°C AND OVER PHOSPHORUS PENTOXIDE IN DESICCATOR AND ASHED

COMPOUND	PERCENTAGE (%)
SiO_2	52.60
Al_2O_3	29.10
Na_2O	0.53
K_2O	3.40
Fe_2O_3	3.25
TiO_2	1.33
Mn_3O_4	0.04
P_2O_5	0.90
CaO	2.57
MgO	1.80
SO_3	0.20

TABLE 4.3 MICROANALYSIS OF TOTAL SEDIMENT

ELEMENT	1	2
CARBON	9.44%	9.00%
HYDROGEN	1.37%	1.34%
NITROGEN	0.16%	0.17%
CHLORINE	0.40%	0.43%
SULPHUR	0.27%	0.32%
PHOSPHORUS	0.85%	0.70%

TABLE 4.4 B.S. 1016 - GRAVIMETRIC ANALYSIS OF TOTAL SEDIMENT

COMPOUND	1	2
MINERAL CARBONATES	2.39%	2.07%
INORGANIC CARBON	0.48%	0.41%

APPENDIX A5

TABLE 5.1 RESULTS OBTAINED FROM X-RAY MEASUREMENTS ON SAMPLES A, B, C, AND D.

SUBSTANCE	FORMULA	d(A)	d(A)	d(A)
Basic Aluminium Silicate	$Al_2Si_2O_5(OH)_4$	1.48_x	2.33	4.34
Basic Aluminium Silicate	$Al_2Si_2O_5(OH)_4$	7.15	3.58_x	2.33
Basic Aluminium Silicate	$Al_2Si_2O_5(OH)_4$	3.58_x	7.15_9	2.32_9
Aluminium Silicate Hydrate	$Al_2Si_2O_5(OH)_4 . 2H_2O$	3.58	7.18_x	1.49_x
Aluminium Silicate Hydrate	$Al_2Si_2O_5(OH)_4$	4.41_x	7.40_9	4.37_7

APPENDIX B.

ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION USING HCl

TABLE B.1 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 5.2

CONDUCTIVITY (λ) = $3.92.10^{-4}ohm^{-1}.m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL(A) = $1.0.\ 10^{-4}.m^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0.10^{-2}$ m.

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$x10^{-2}$
V(volt)	60.78	60.81	60.80	60.82	60.81	60.83	60.79	
I(amp)	62.21	62.24	62.23	62.24	62.24	62.26	62.22	$x10^{-6}$
R(ohm)	9.77	9.77	9.77	9.77	9.77	9.77	9.77	$x10^{5}$
l(m)	3.83	3.83	3.83	3.83	3.83	3.83	3.83	$x10^{-2}$
E(volt m^{-1})	15.87	15.88	15.88	15.88	15.88	15.88	15.87	$x10^{2}$
	17.8	17.2	15.2	14.6	14.8	16.2	16.4	
	18.0	16.8	15.4	14.4	15.2	16.6	17.0	
	18.2	16.6	15.8	15.0	15.0	17.0	17.2	
	17.6	16.4	16.0	15.0	15.6	17.0	16.8	
	17.4	17.0	16.0	14.2	16.0	16.4	16.8	
	17.8	16.2	15.6	14.8	15.8	16.6	17.4	
	17.6	16.6	15.6	14.2	15.4	16.2	17.6	
	18.0	16.2	15.8	14.6	15.2	16.8	17.2	
	18.0	17.0	16.0	15.0	15.4	16.4	17.4	
	17.6	16.4	15.2	14.0	16.0	16.2	16.6	
	18.2	16.4	15.2	14.2	15.2	16.8	16.8	
	18.2	17.0	15.6	14.0	15.8	17.0	17.2	
	18.4	17.2	15.4	14.4	15.0	16.6	17.4	
	18.4	16.6	15.8	14.8	16.0	16.4	17.0	
	18.0	16.8	15.4	14.6	15.6	16.6	17.6	
	18.0	16.8	15.0	14.0	15.6	16.8	17.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVEISION SCREEN

TABLE B.2 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 5.2

CONDUCTIVITY (λ) = $3.92.10^{-4}$ ohm.$^{-1}$m^{-1}

CROSS-SECTION AREA OF THE ELECTROPHORETIC CELL (A) = $1.0.\ 10^{-4}\ m^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0.10^{-2}$m.

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$x10^{-2}$
V(volt)	60.82	60.78	60.80	60.81	60.82	60.79	60.83	
I(amp)	62.24	62.21	62.23	62.24	62.24	62.22	62.26	$x10^{-6}$
R(ohm)	9.77	9.77	9.77	9.77	9.77	9.77	9.77	$x10^{5}$
l(m)	3.83	3.83	3.83	3.83	3.83	3.83	3.83	$x10^{-2}$
E(volt m^{-1})	15.88	15.87	15.88	15.87	15.88	15.87	15.88	$x10^{2}$
	17.6	16.8	15.8	14.6	15.4	16.4	17.2	
	17.8	16.6	16.2	14.4	15.8	16.2	17.4	
	17.4	17.2	16.4	15.0	16.2	16.8	17.8	
	18.0	17.0	16.0	15.4	16.8	17.2	18.2	
	18.6	16.6	15.6	14.8	16.0	17.2	18.0	
	18.4	17.4	16.0	14.4	15.6	16.6	17.2	
	18.2	16.8	16.2	15.2	16.4	17.0	17.6	
	18.0	17.4	16.6	15.4	16.6	16.6	17.2	
	18.4	17.6	16.2	14.8	16.0	16.8	17.8	
	17.6	17.2	15.6	15.0	16.2	17.0	17.6	
	18.2	17.0	15.8	14.6	15.4	16.4	18.0	
	17.4	17.4	16.4	15.4	16.8	16.6	17.2	
	18.0	17.2	16.6	15.2	15.6	16.2	18.2	
	18.4	17.6	16.2	15.0	16.4	16.4	18.0	
	18.2	17.4	16.4	14.8	16.6	16.2	17.4	
	18.0	17.0	16.0	14.4	15.8	16.6	17.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.3 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 4.5

CONDUCTIVITY (λ) = 16.0 $10^{-4} ohm^{-1} m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 14.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	x10^{-2}
V(volt)	58.06	58.06	58.10	58.08	58.05	58.06	58.07	
I(amp)	241.9	241.9	242.0	242.0	241.8	241.9	241.9	x10^{-6}
R(ohm)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	x10^{5}
l(m)	3.84	3.84	3.84	3.84	3.84	3.84	3.84	x10^{-2}
E(volt m^{-1})	15.12	15.12	15.13	15.13	15.11	15.12	15.12	x10^{2}
	16.2	15.2	14.2	13.2	13.8	14.6	15.4	
	16.4	15.6	14.6	13.0	14.2	15.2	16.2	
	16.0	15.8	14.8	13.6	14.6	14.8	16.0	
	16.2	16.0	14.4	14.0	14.0	15.0	15.6	
	15.8	15.0	15.0	14.2	14.4	15.4	16.0	
	16.4	15.0	14.4	13.8	14.6	14.6	15.8	
	16.0	15.4	14.2	13.2	13.8	15.6	16.4	
	15.8	15.8	14.8	13.4	14.0	15.0	16.0	
	16.6	15.6	15.0	13.4	13.6	15.4	15.6	
	16.0	15.0	14.4	13.8	14.0	15.2	15.4	
	16.4	15.4	15.0	14.0	13.6	14.6	16.0	
	16.2	15.2	14.8	13.6	13.8	14.8	16.4	
	15.8	15.8	14.2	13.4	14.2	15.0	15.8	
	16.0	15.0	14.4	14.2	14.4	15.4	16.0	
	16.4	16.0	14.2	13.0	14.2	14.8	15.8	
	15.8	15.4	14.6	13.4	14.4	15.2	15.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.4 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 4.5

CONDUCTIVITY (λ)	= 16.0 10^{-4} ohm^{-1} m^{-1}
CROSS-SECTION AREA OF THE ELECTROPHORETIC CELL (A)	= 1.0 10^{-4} m^2
DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X)	= 14.0 10^{-2} m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE							
d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$x10^{-2}$
V(volt)	58.10	58.09	58.10	58.07	58.09	58.08	58.10	
I(amp)	242.0	241.9	242.0	241.9	241.9	242.0	242.0	$x10^{-6}$
R(ohm)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	$x10^{5}$
l(m)	3.84	3.84	3.84	3.84	3.84	3.84	3.84	$x10^{-2}$
E(volt m^{-1})	15.13	15.12	15.13	15.12	15.12	15.13	15.13	$x10^{2}$
	16.4	15.2	14.2	13.4	14.4	15.6	16.4	
	16.6	16.0	14.6	13.8	14.8	15.4	16.2	
	16.8	16.2	14.8	14.0	15.2	15.2	15.8	
	16.0	15.6	15.2	14.2	15.0	16.0	16.0	
	16.6	15.4	15.4	13.6	14.6	16.2	15.6	
	16.2	15.8	15.0	13.2	14.8	15.8	16.4	
	16.0	15.2	14.8	14.0	15.0	16.0	16.6	
	15.8	15.6	15.2	13.6	14.4	15.6	16.4	
	15.6	16.0	14.4	13.0	14.6	15.4	16.0	
	15.8	15.8	14.8	13.4	15.2	15.0	15.8	
	16.2	15.6	15.4	13.2	14.6	15.4	15.6	
	15.6	15.0	14.4	14.0	14.8	15.0	16.4	
	16.0	15.2	15.2	13.6	15.0	14.2	16.0	
	15.4	15.4	15.0	13.0	15.2	15.4	15.8	
	16.8	16.2	14.6	14.2	14.4	15.8	16.0	
	16.0	16.0	15.0	13.4	14.4	15.8	16.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.5 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 4.0

CONDUCTIVITY (λ) = 54.0 10^{-4}ohm^{-1}m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4}m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 14.0 10^{-2}m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	x10^{-2}
V(volt)	58.20	58.21	58.22	58.24	58.20	58.23	58.21	
I(amp)	816.4	816.6	816.8	817.0	816.4	816.9	816.6	x10^{-6}
R(ohm)	7.129	7.128	7.128	7.129	7.129	7.128	7.129	x10^{4}
l(m)	3.85	3.85	3.85	3.85	3.85	3.85	3.85	x10^{-2}
E(volt m^{-1})	15.12	15.12	15.13	15.13	15.12	15.13	15.12	x10^{2}
	15.2	14.6	13.8	12.8	13.2	14.0	14.6	
	15.0	14.8	14.0	13.2	13.8	13.8	15.2	
	14.8	14.4	13.2	13.0	14.2	14.2	15.0	
	15.4	14.2	13.0	12.6	13.6	14.6	14.8	
	14.6	14.8	13.8	12.4	13.4	14.0	15.2	
	14.8	14.0	13.4	12.0	13.0	14.8	15.4	
	15.2	14.6	13.2	13.0	13.6	14.4	14.6	
	15.4	14.4	13.6	12.4	14.0	14.6	14.8	
	14.6	14.2	13.0	12.2	13.6	14.4	15.4	
	15.2	14.0	13.4	12.6	13.0	14.2	15.0	
	14.6	14.2	14.0	12.8	13.2	13.8	15.4	
	15.0	14.6	13.6	13.0	14.0	14.0	14.8	
	15.2	14.0	13.4	12.2	13.8	14.8	15.0	
	14.8	14.8	13.0	12.6	13.4	14.6	15.2	
	15.0	14.8	13.8	13.2	13.6	14.2	15.2	
	14.8	14.2	13.2	12.0	13.2	14.4	14.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVEISION SCREEN

TABLE B.6 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 4.0

CONDUCTIVITY (λ) = 54.0 10^{-4} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE TELEVISION SCREEN (X) = 14.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE								
d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	x10^{-2}
V(volt)	58.24	58.19	58.22	58.18	58.19	58.21	58.23	
I(amp)	817.0	816.3	816.8	816.2	816.3	816.6	816.9	x10^{-6}
R(ohm)	7.129	7.129	7.128	7.128	7.129	7.128	7.128	x10^{4}
l(m)	3.85	3.85	3.85	3.85	3.85	3.85	3.85	10^{-2}
E(volt M^{-1})	15.13	15.12	15.13	15.11	15.12	15.12	15.13	10^{2}
	14.6	14.6	13.2	12.4	13.4	14.2	14.6	
	14.4	14.0	13.6	12.8	13.2	14.6	15.2	
	14.2	14.2	14.0	13.0	13.8	15.0	15.0	
	15.0	13.8	13.8	12.4	14.0	15.0	15.4	
	14.8	14.0	13.6	12.8	13.6	14.8	15.6	
	14.6	14.4	13.2	12.6	13.0	15.2	14.8	
	15.2	14.8	14.2	12.2	13.8	14.4	15.0	
	14.4	14.2	13.4	12.4	14.0	14.6	15.4	
	15.2	14.0	13.8	12.0	13.6	15.0	15.2	
	14.8	14.4	13.4	12.2	13.8	14.2	14.8	
	14.4	14.2	13.2	12.0	13.4	14.8	14.6	
	14.8	14.2	14.0	12.4	13.0	14.4	15.0	
	15.0	14.6	13.4	12.6	14.0	14.2	15.6	
	14.2	14.8	13.6	13.0	13.6	14.6	15.2	
	14.6	14.6	13.4	12.8	14.0	14.8	15.6	
	14.8	14.8	14.2	12.0	13.8	14.4	15.4	

TIME (SEC)TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.7 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.8

CONDUCTIVITY (λ) = $94.0\ 10^{-4}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	x10^{-2}
V(volt)	58.31	58.28	58.29	58.30	58.28	58.29	58.31	
I(amp)	1.424	1.422	1.423	1.424	1.422	1.423	1.424	x10^{-3}
R(ohm)	4.10	4.10	4.10	4.10	4.10	4.10	4.10	x10^{4}
l(m)	3.85	3.85	3.85	3.85	3.85	3.85	3.85	10^{-2}
E(volt m^{-1})	15.15	15.12	15.14	15.15	15.12	15.14	15.15	10^{2}
	13.4	12.8	12.2	10.6	11.0	12.6	13.6	
	13.0	12.6	12.0	10.8	11.4	12.0	13.0	
	13.6	12.4	11.6	11.2	11.6	12.4	12.8	
	13.4	12.2	11.4	11.0	11.0	12.8	13.4	
	14.0	12.8	11.8	10.4	11.8	12.2	13.6	
	13.2	13.0	12.2	11.2	11.4	12.2	13.2	
	13.6	12.0	11.2	10.2	11.2	13.0	14.0	
	13.8	12.4	11.4	10.0	11.6	12.6	14.0	
	13.6	12.0	11.8	10.4	11.4	12.8	13.8	
	13.2	12.8	12.0	10.8	11.0	12.8	14.2	
	13.8	12.6	11.4	11.0	11.8	12.4	13.4	
	13.0	12.0	11.2	10.6	11.2	12.0	13.2	
	13.2	13.0	11.6	10.2	11.6	12.2	14.2	
	13.0	12.4	11.4	10.4	11.4	12.0	12.8	
	14.0	12.8	11.6	10.0	11.2	12.6	13.0	
	13.4	12.6	11.8	10.0	11.4	12.4	13.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.8 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.8

CONDUCTIVITY (λ) = $94.0\ 10^{-4}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0.10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$\times 10^{-2}$
V(volt)	58.26	58.27	58.25	58.26	58.27	58.28	58.28	
I(amp)	1.422	1.42	1.422	1.422	1.422	1.422	1.422	$\times 10^{-3}$
R(ohm)	4.10	4.10	4.10	4.10	4.10	4.10	4.10	$\times 10^{4}$
l(m)	3.86	3.86	3.86	3.86	3.86	3.85	3.85	$\times 10^{-2}$
E(volt m^{-1})	15.11	15.11	15.11	15.11	15.11	15.13	15.13	$\times 10^{2}$
	13.6	12.0	11.4	10.4	11.0	12.4	12.8	
	14.4	13.0	11.8	10.8	11.2	12.6	13.2	
	14.2	13.4	12.0	11.0	11.6	12.2	13.8	
	13.8	12.8	11.6	10.2	11.0	12.0	13.6	
	13.4	13.2	12.4	10.0	11.8	13.2	14.0	
	13.0	13.0	12.0	10.2	11.4	13.0	13.4	
	14.0	12.6	11.6	10.0	11.6	12.8	13.2	
	13.2	12.4	11.4	10.4	11.4	13.0	12.8	
	13.4	13.2	11.2	10.6	11.2	13.0	13.0	
	13.2	12.6	11.8	10.8	11.8	12.6	13.0	
	13.0	12.4	12.0	10.6	12.0	12.8	13.6	
	14.4	12.0	11.4	10.2	11.4	12.4	13.4	
	13.8	13.4	11.8	10.0	12.0	12.4	13.8	
	13.6	12.8	11.6	10.0	11.0	12.6	14.0	
	14.2	12.0	12.4	10.4	11.4	12.2	13.2	
	14.0	12.6	11.8	10.2	11.2	12.8	13.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.9 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.5

CONDUCTIVITY (λ) = $240.0\ 10^{-4}\ \text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \text{m}^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$\times 10^{-2}$
V(volt)	54.51	54.48	54.49	54.50	54.47	54.49	54.48	
I(amp)	3.40	3.40	3.40	3.40	3.40	3.40	3.40	$\times 10^{-3}$
R(ohm)	1.603	1.602	1.603	1.603	1.602	1.603	1.602	$\times 10^{3}$
l(m)	3.85	3.85	3.85	3.85	3.84	3.85	3.85	$\times 10^{-2}$
E(volt m^{-1})	14.17	14.16	14.17	14.17	14.17	14.17	14.16	$\times 10^{2}$

12.4	11.2	10.8	9.6	10.6	11.0	13.6
12.0	11.6	10.2	9.2	10.8	12.0	13.8
12.2	11.8	10.6	9.8	11.0	11.6	13.4
12.0	11.4	10.4	9.0	11.2	11.2	14.0
12.6	11.0	10.6	10.2	10.0	11.4	14.2
12.2	12.0	10.0	10.0	10.4	11.2	13.8
12.4	11.8	10.2	9.8	10.2	11.8	13.4
12.8	11.2	10.4	9.4	10.8	11.4	14.0
12.0	11.4	10.0	9.4	11.0	11.8	13.4
12.2	11.6	10.4	9.8	10.6	11.6	13.6
12.8	12.0	10.8	9.2	10.2	11.0	14.2
12.6	11.2	10.6	10.0	10.4	11.2	13.6
12.8	11.0	10.0	9.0	11.0	12.0	14.0
12.4	11.4	10.2	9.4	10.6	11.2	13.8
12.0	11.6	10.6	9.6	10.4	11.6	13.8
12.4	11.8	10.2	9.6	10.2	11.2	14.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.10 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.5

CONDUCTIVITY (λ) = $240.0\ 10^{-4}\ \text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \text{m}^{2}$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	$\times 10^{-2}$
V(volt)	54.51	54.50	54.52	54.47	54.52	54.48	54.50	
I(amp)	3.40	3.40	3.40	3.40	3.40	3.40	3.40	$\times 10^{-3}$
R(ohm)	1.603	1.603	1.604	1.602	1.604	1.602	1.603	$\times 10^{3}$
l(m)	3.85	3.85	3.85	3.84	3.85	3.85	3.85	$\times 10^{-2}$
E(volt m^{-1})	14.17	14.17	14.17	14.17	14.17	14.17	14.17	$\times 10^{2}$
	12.6	11.2	10.2	9.8	10.8	11.6	12.2	
	13.4	11.4	10.0	9.6	10.6	11.8	13.0	
	12.8	11.6	10.4	10.2	10.8	12.2	12.8	
	13.0	12.2	10.0	10.4	11.2	12.4	13.2	
	12.8	12.0	10.8	9.6	11.4	11.8	13.4	
	13.0	11.6	11.0	10.0	11.0	12.0	12.6	
	13.2	11.2	11.2	9.4	10.8	11.8	12.4	
	12.6	11.8	10.6	9.8	11.6	12.4	13.0	
	13.4	11.6	11.0	10.4	11.6	12.2	12.4	
	13.6	11.8	10.6	10.0	11.0	11.6	13.2	
	13.6	12.0	10.8	9.8	10.6	12.2	12.6	
	13.0	11.4	11.0	9.4	11.4	12.0	13.0	
	12.6	11.6	10.2	9.6	11.0	12.0	12.8	
	12.8	11.2	10.4	10.2	11.2	11.8	12.2	
	13.2	12.2	10.2	9.8	10.6	12.4	13.4	
	12.8	11.4	10.8	9.4	10.8	11.6	12.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.11 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.0

CONDUCTIVITY (λ) = $730.0.\ 10^{-4}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $14.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE								
d(m)	3.70	3.80	3.90	4.00	4.10	4.20	4.30	x10^{-2}
V(volt)	47.41	47.43	47.42	47.45	47.40	47.44	47.42	
I(amp)	9.0	9.0	9.0	9.0	9.10	9.0	9.0	x10^{-3}
R(ohm)	5.27	5.27	5.27	5.27	5.27	5.27	5.27	x10^{3}
l(m)	3.85	3.85	3.85	3.85	3.84	3.85	3.85	x10^{-2}
E(volt m^{-1})	12.33	12.33	12.33	12.33	12.33	12.33	12.33	x10^{2}
	12.6	11.6	11.0	9.2	10.6	12.6	13.8	
	13.0	11.8	10.6	9.6	10.8	12.4	14.2	
	12.8	11.8	10.8	10.0	11.2	12.8	13.2	
	13.2	11.4	11.2	10.2	11.6	12.0	13.4	
	12.6	12.0	11.4	10.0	11.4	12.2	14.0	
	13.4	12.2	10.8	9.2	10.8	13.0	13.6	
	12.4	11.2	10.4	9.8	11.2	12.8	13.4	
	13.0	11.4	10.2	9.4	11.0	12.6	14.2	
	12.8	11.0	10.4	9.0	11.0	12.4	13.6	
	13.2	11.4	11.2	9.4	11.6	12.2	13.2	
	13.4	11.6	10.6	9.0	10.6	13.0	14.0	
	12.4	12.2	10.2	9.6	10.8	12.0	14.2	
	12.6	11.4	10.8	10.2	11.2	12.0	13.8	
	12.4	11.2	11.0	9.8	11.4	12.6	13.4	
	13.0	12.2	10.6	9.4	11.0	12.4	13.6	
	12.6	11.8	10.4	9.2	11.4	12.8	13.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE B.12 ELECTROPHORESIS OF 100ppm QUARTZ SUSPENSION AT pH = 3.0

CONDUCTIVITY (λ) = 730.0 10^{-4}ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 14.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.80	3.90	4.0	4.10	4.20	4.30	x10^{-2}
V(volt)	47.43	47.43	47.45	47.41	47.42	47.44	47.43	
I(amp)	9.0	9.0	9.0	9.0	9.0	9.0	9.0	x10^{-3}
R(ohm)	5.27	5.27	5.27	5.27	5.27	5.27	5.27	x10^{3}
l(m)	3.85	3.85	3.85	3.85	3.85	3.85	3.85	x10^{-2}
E(volt m^{-1})	12.33	12.33	12.33	12.33	12.33	12.33	12.33	x10^{2}
	13.6	12.6	11.2	9.8	10.8	11.8	13.4	
	13.8	12.4	10.6	10.6	11.0	12.2	13.0	
	13.2	13.0	11.8	10.8	11.2	12.4	13.6	
	13.0	12.8	11.0	11.0	10.8	12.0	13.2	
	13.4	12.2	11.4	9.4	11.4	11.8	13.0	
	13.2	12.0	10.8	9.2	10.6	12.0	13.6	
	14.4	12.8	11.6	9.6	11.8	12.6	13.8	
	14.2	12.6	11.0	10.4	11.6	12.8	14.2	
	14.4	11.8	11.6	9.4	11.8	12.4	14.0	
	13.0	11.6	11.2	9.6	11.4	12.0	13.8	
	13.6	12.4	10.8	9.8	11.6	12.2	13.4	
	13.2	12.2	10.6	10.2	10.6	12.6	13.2	
	14.8	12.0	11.8	10.4	11.2	12.0	13.4	
	14.2	11.6	11.2	10.2	11.4	12.8	14.2	
	14.8	12.0	11.4	9.2	11.0	11.8	14.0	
	13.0	11.8	11.4	10.0	10.8	12.4	13.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

APPENDIX C

ELECTROPHORESIS OF COLLIERY WASTE-WATER USING HCl

TABLE C.1 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.6

CONDUCTIVITY (λ) = 1.36 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	18.46	18.47	18.47	18.51	18.51	18.49	
I(amp)	2.93	2.93	2.93	2.94	2.94	2.93	x10^{-3}
R(ohm)	6.30	6.30	6.30	6.30	6.30	6.30	x10^{3}
l(m)	8.568	8.573	8.573	8.562	8.562	8.582	x10^{-2}
E(volt m^{-1})	2.15	2.15	2.15	2.16	2.16	2.15	x10^{2}

18.2	15.4	14.8	13.6	14.2	16.8
18.8	16.2	14.2	13.2	13.8	15.6
19.2	16.6	15.0	13.8	14.0	16.2
18.6	16.0	14.6	14.0	14.6	15.8
20.4	16.8	14.0	13.4	14.0	16.2
20.6	16.8	14.4	13.8	13.6	16.4
19.8	16.2	14.2	13.2	14.2	16.0
18.0	16.8	14.6	13.2	13.8	16.2
18.0	17.2	15.0	13.6	14.2	16.2
18.8	15.6	14.8	13.4	14.6	15.8
19.4	16.4	14.0	14.2	13.6	16.4
19.8	16.6	14.6	14.0	13.6	16.0
20.2	17.0	14.8	13.4	13.8	16.0
18.0	17.6	14.4	13.8	14.0	15.6
18.6	15.8	14.8	13.6	14.4	15.8
19.8	15.6	15.2	13.0	14.8	15.8
18.4	15.8	15.0	13.6	13.8	16.2
18.8	16.6	15.0	13.4	14.2	16.4

TIME TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN (SEC).

TABLE C.2 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.6

CONDUCTIVITY (λ) = $1.36\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	18.57	18.58	18.56	18.55	18.57	18.59	
I(amp)	2.95	2.95	2.95	2.94	2.95	2.95	$x10^{-3}$
R(ohm)	6.29	6.29	6.29	6.31	6.29	6.30	$x10^{3}$
l(m)	8.56	8.57	8.56	8.58	8.56	8.57	$x10^{-2}$
E(volt m^{-1})	2.169	2.169	2.167	2.162	2.169	2.169	$x10^{2}$
	19.6	17.2	15.8	13.8	14.6	16.8	
	20.2	17.0	15.2	13.4	14.8	16.4	
	20.0	16.6	15.0	14.0	14.8	17.2	
	18.8	16.0	14.8	13.8	15.2	17.0	
	18.0	16.8	15.0	13.2	15.4	16.4	
	18.6	16.2	14.4	13.6	14.6	17.6	
	19.6	17.0	14.0	14.0	14.4	17.2	
	19.2	16.4	14.2	13.0	15.0	16.8	
	18.8	16.8	14.8	13.6	15.4	17.0	
	20.0	17.2	14.6	12.8	15.4	17.6	
	19.8	16.6	14.0	13.4	14.8	17.8	
	18.6	16.2	14.8	14.2	14.6	17.4	
	19.8	17.0	14.6	13.2	15.4	18.0	
	20.0	17.2	14.2	13.8	15.8	18.2	
	18.4	16.0	13.4	13.4	15.2	17.4	
	18.2	16.8	14.6	14.0	16.0	17.6	
	18.6	16.4	14.2	14.2	16.0	18.2	
	18.2	16.6	13.8	13.2	15.6	18.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.3 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.6

CONDUCTIVITY (λ) = $1.36\ 10^{-1}\ \mathrm{ohm}^{-1}\ \mathrm{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \mathrm{m}^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$\times 10^{-2}$
V(volt)	18.55	18.55	18.56	18.58	18.54	18.51	
I(amp)	2.94	2.94	2.94	2.94	2.94	2.94	$\times 10^{-3}$
R(ohm)	6.31	6.31	6.31	6.31	6.31	6.30	$\times 10^{3}$
l(m)	8.58	8.58	8.58	8.57	8.58	8.56	$\times 10^{-2}$
E(volt m^{-1})	2.16	2.16	2.16	2.17	2.16	2.16	$\times 10^{2}$

19.2	15.8	14.2	12.8	13.0	15.6
18.6	15.6	13.8	12.4	14.2	15.2
18.8	16.4	14.6	13.4	13.8	16.0
19.0	16.0	14.0	13.6	12.8	16.2
18.2	15.8	14.4	12.6	13.4	15.8
18.6	16.2	13.8	12.2	13.0	16.4
17.8	16.0	15.2	12.8	12.8	16.0
19.2	15.6	15.0	13.0	14.0	15.6
18.0	16.4	14.8	13.0	14.6	15.4
18.0	16.8	14.2	13.4	14.4	15.0
17.8	16.8	15.0	12.8	13.8	15.6
18.4	15.6	14.6	12.6	13.4	16.2
18.4	15.8	13.8	13.0	14.0	16.6
18.2	16.6	15.2	12.4	14.2	15.8
17.6	16.0	15.0	13.6	12.8	16.4
17.8	16.6	14.4	12.8	13.2	15.4
18.6	16.8	14.6	12.4	13.6	16.0
18.8	16.2	14.0	12.2	13.4	16.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.4 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.6

CONDUCTIVITY (λ) = $1.36\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	18.56	18.50	18.53	18.54	18.52	18.51	
I(amp)	2.95	2.94	2.94	2.94	2.94	2.94	x10^{-3}
R(ohm)	6.30	6.30	6.30	6.30	6.30	6.30	x10^{3}
l(m)	8.56	8.56	8.56	8.56	8.56	8.56	x10^{-2}
E(volt m^{-1})	2.17	2.16	2.16	2.16	2.16	2.16	x10^{2}
	21.0	15.2	14.8	13.2	13.6	15.2	
	21.2	15.6	15.2	13.0	13.6	15.6	
	21.2	15.0	14.8	13.2	13.2	15.4	
	20.8	14.6	15.0	12.8	13.4	16.6	
	19.8	14.8	14.6	13.0	14.0	16.2	
	20.6	15.4	14.6	13.4	14.2	16.0	
	21.0	15.6	14.8	12.6	13.8	15.4	
	21.0	16.2	14.2	12.2	14.4	16.6	
	20.6	14.6	14.0	13.0	14.6	15.8	
	20.8	16.0	14.4	12.8	14.0	15.8	
	20.4	15.2	14.2	12.4	14.4	16.4	
	20.4	16.4	14.6	12.2	13.2	16.2	
	21.2	14.8	13.8	13.2	13.8	15.4	
	20.6	15.4	14.0	13.2	14.0	16.0	
	21.0	15.8	13.6	12.8	13.4	16.0	
	20.8	15.0	13.8	12.2	14.6	15.6	
	19.8	15.6	13.4	12.8	14.2	15.8	
	20.4	16.2	14.2	12.6	14.6	16.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN.

TABLE C.5 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.8

CONDUCTIVITY (λ) = $1.38\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	18.20	18.23	18.21	18.23	18.23	18.24	
I(amp)	2.93	2.94	2.94	2.94	2.94	2.94	$x10^{-3}$
R(ohm)	6.21	6.20	6.20	6.20	6.20	6.20	$x10^{3}$
l(m)	8.57	8.56	8.55	8.56	8.56	8.56	$x10^{-2}$
E(volt M^{-1})	2.12	2.13	2.13	2.13	2.13	2.13	$x10^{2}$
	17.6	17.0	14.0	13.0	13.6	14.8	
	17.4	16.8	14.2	13.4	13.8	15.0	
	17.8	16.8	13.8	12.8	13.4	14.6	
	18.0	16.0	14.2	13.0	14.0	15.4	
	17.6	16.4	14.8	13.6	13.4	15.4	
	18.0	15.8	14.4	13.2	13.6	15.0	
	17.2	15.6	14.2	12.6	13.2	14.8	
	17.6	15.8	14.6	12.8	13.8	15.2	
	19.8	15.4	14.8	13.2	14.2	14.6	
	17.2	15.2	14.8	13.4	14.0	14.8	
	17.0	15.8	14.6	12.6	13.4	15.2	
	18.2	15.2	14.2	13.2	13.8	14.6	
	17.2	16.0	14.6	13.6	13.2	15.2	
	17.8	15.4	14.4	12.8	14.2	15.4	
	17.4	15.6	14.0	13.4	14.0	14.6	
	17.6	15.4	13.8	13.0	13.6	14.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.6 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.8

CONDUCTIVITY (λ) = $1.38\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	18.22	18.25	18.24	18.25	18.21	18.23	
I(amp)	2.94	2.94	2.94	2.94	2.94	2.94	x10^{-3}
R(ohm)	6.19	6.21	6.20	6.21	6.20	6.20	x10^{3}
l(m)	8.55	8.57	8.56	8.57	8.55	8.56	x10^{-2}
E(volt m^{-1})	2.13	2.13	2.13	2.13	2.13	2.13	x10^{2}

19.4	16.4	15.2	14.8	14.8	16.8
20.2	16.6	15.6	13.8	15.2	17.4
19.6	17.2	15.0	14.2	15.6	17.0
19.2	16.8	15.8	14.4	16.2	16.6
19.8	15.8	14.8	14.0	16.0	17.2
19.4	16.2	15.0	13.8	15.4	16.8
19.0	16.8	15.4	13.4	15.0	16.6
20.2	16.4	15.8	14.0	14.8	17.0
19.6	16.2	14.6	13.2	16.4	17.4
19.0	16.0	14.8	13.6	16.0	16.6
19.8	15.8	15.2	14.4	15.6	16.8
19.8	16.4	14.8	14.0	15.4	17.2
19.2	16.6	15.6	13.6	15.8	16.8
20.0	16.8	15.4	13.2	16.2	17.0
20.0	15.8	15.0	14.2	15.6	17.4
19.8	15.8	14.6	13.4	15.8	17.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.7 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.8

CONDUCTIVITY (λ) = $1.38\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	18.43	18.47	18.44	18.45	18.46	18.47	
I(amp)	2.97	2.98	2.97	2.97	2.97	2.97	$x10^{-3}$
R(ohm)	6.21	6.20	6.21	6.21	6.22	6.22	$x10^{3}$
l(m)	8.56	8.55	8.57	8.57	8.58	8.58	$x10^{-2}$
E(volt m^{-1})	2.15	2.16	2.15	2.15	2.15	21.5	$x10^{2}$
	16.8	15.4	14.2	12.8	14.2	15.0	
	16.4	15.2	14.0	12.4	13.8	15.8	
	17.0	15.8	13.6	13.0	13.6	16.2	
	16.8	16.2	13.8	13.2	14.0	16.0	
	16.2	16.0	14.2	12.6	14.6	15.8	
	17.0	15.6	13.6	12.4	13.8	15.6	
	16.8	15.2	14.2	12.6	14.8	15.4	
	16.6	15.6	13.8	12.8	15.2	16.0	
	16.2	15.8	13.4	13.2	15.0	15.4	
	16.0	15.0	13.8	12.4	14.6	16.2	
	16.4	15.6	13.6	12.8	13.8	15.2	
	16.2	15.8	13.4	12.2	14.4	15.8	
	16.6	15.2	14.0	12.8	14.8	15.0	
	16.0	16.0	13.8	12.0	13.6	15.2	
	16.8	15.4	13.4	12.6	14.4	15.8	
	16.6	15.6	13.6	12.0	14.2	15.4	

TIME (SEC) TAKEN BY THE PARTICLES TO TRAVEL ON THE TELEVISION SCREEN

TABLE C.8 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.8

CONDUCTIVITY (λ) = $1.38\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	18.45	18.48	18.49	18.51	18.47	18.50	
I(amp)	2.97	2.98	2.98	2.99	2.98	2.98	$x10^{-3}$
R(ohm)	6.21	6.20	6.21	6.19	6.20	6.21	$x10^{3}$
l(m)	8.57	8.56	8.56	8.54	8.55	8.57	$x10^{-2}$
E(volt m^{-1})	2.15	2.16	2.16	2.17	2.16	2.16	$x10^{2}$
	20.2	14.8	13.2	12.2	14.6	16.2	
	19.8	14.8	12.8	11.6	14.0	15.8	
	19.2	15.4	12.4	11.6	14.4	16.2	
	19.4	15.6	13.0	12.0	14.4	15.6	
	19.8	14.6	12.2	12.2	15.0	16.0	
	19.4	15.0	12.8	11.8	15.2	15.4	
	20.0	14.4	12.6	12.2	14.8	15.8	
	20.0	14.2	13.2	11.6	14.6	15.6	
	19.6	15.0	12.4	11.4	14.2	15.4	
	19.4	14.2	13.2	11.8	14.8	15.8	
	19.8	14.6	12.8	11.2	14.4	16.2	
	19.2	14.2	12.4	12.0	14.2	16.0	
	19.6	14.8	12.8	12.0	14.2	15.4	
	19.6	14.6	12.6	11.6	14.0	15.6	
	19.0	14.4	12.2	11.2	14.6	15.4	
	19.2	14.6	12.4	11.4	14.0	15.8	

TIME (SEC) TAKEN BY THE PARTICLES TO TRAVEL ON THE TELEVISION SCREEN

TABLE C.9 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = 1.44 10^{-1} $ohm^{-1}m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	17.85	17.89	17.87	17.90	17.87	17.88	
I(amp)	3.00	3.01	3.0	3.01	3.01	3.01	x10^{-3}
R(ohm)	5.93	5.95	5.94	5.95	5.94	5.94	x10^{3}
l(m)	8.57	8.56	8.55	8.56	8.55	8.55	x10^{-2}
E(volt m^{-1})	2.08	2.09	2.09	2.09	2.09	2.09	x10^{2}

15.6	15.6	13.6	12.2	12.8	14.6
15.4	15.8	13.4	12.4	13.2	15.8
16.2	15.0	12.8	12.0	12.8	15.0
16.0	14.6	12.8	12.4	13.4	14.4
15.4	14.8	13.2	12.8	12.6	13.8
15.8	15.2	13.4	11.8	13.6	14.2
16.8	14.8	12.6	11.6	12.8	15.4
16.2	15.6	12.6	11.8	13.4	15.8
16.2	14.6	13.4	11.8	13.2	14.8
16.4	14.8	13.0	12.2	13.4	14.2
15.6	14.2	12.4	12.8	13.2	14.6
16.4	14.8	12.8	12.6	13.0	15.4
16.8	15.0	12.4	11.6	12.8	14.6
16.0	14.4	13.6	12.4	13.4	14.6
16.6	15.2	13.2	12.8	12.6	14.2
15.8	15.0	13.4	11.4	12.4	14.6

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.10 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.44\ 10^{-1}$ ohm^{-1}m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	10^{-2}
V(volt)	17.90	17.93	17.94	17.92	17.91	17.93	
I(amp)	3.01	3.02	3.02	3.01	3.01	3.02	10^{-3}
R(ohm)	5.95	5.94	5.94	5.95	5.95	5.94	10^{3}
l(m)	8.56	8.55	8.55	8.57	8.57	8.55	10^{-2}
E(volt m^{-1})	2.09	2.10	2.10	2.09	2.09	2.10	10^{2}
	18.2	16.6	14.2	13.6	15.0	16.6	
	18.6	16.2	13.6	13.2	15.4	16.2	
	17.8	15.6	13.2	13.0	15.2	16.0	
	17.4	16.8	14.0	13.8	16.4	16.4	
	18.0	15.2	13.8	13.2	16.0	16.8	
	18.8	16.0	14.2	13.6	16.2	17.0	
	18.2	15.8	13.4	13.4	15.4	16.2	
	18.2	15.6	13.8	13.8	15.8	16.8	
	18.8	15.4	13.6	14.2	16.4	16.4	
	18.4	15.6	13.4	14.0	15.8	16.8	
	17.6	15.2	13.0	13.2	15.2	16.0	
	18.6	15.0	14.2	13.6	15.6	16.2	
	18.0	15.4	13.8	13.8	15.6	17.0	
	18.4	15.8	13.4	14.0	15.4	16.8	
	17.8	15.0	13.2	13.4	16.2	16.4	
	18.0	15.2	13.6	13.6	15.8	16.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.11 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.44\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$\times 10^{-2}$
V(volt)	18.15	18.19	18.17	18.20	18.12	18.17	
I(amp)	3.05	3.06	3.06	3.06	3.04	3.06	$\times 10^{-3}$
R(ohm)	5.95	5.94	5.94	5.95	5.96	5.94	$\times 10^{3}$
l(m)	8.57	8.56	8.56	8.56	8.58	8.56	$\times 10^{-2}$
E(volt m^{-1})	2.12	2.13	2.12	2.13	2.11	2.13	$\times 10^{2}$

15.4	14.6	13.2	12.2	13.8	14.8
15.0	14.8	12.8	11.8	14.2	14.6
15.6	14.2	13.2	11.4	13.6	15.2
15.2	14.6	12.6	12.0	14.4	15.0
16.2	14.4	12.4	11.8	14.6	15.6
16.0	15.0	13.0	11.6	13.8	15.8
15.6	15.4	13.4	12.2	14.0	16.0
15.4	15.0	12.8	12.0	14.4	14.8
15.2	14.8	12.8	12.6	13.4	15.4
15.8	14.0	12.4	11.4	13.8	15.6
15.8	14.6	13.0	11.8	14.4	15.2
15.0	14.4	13.0	12.2	14.8	15.8
15.2	14.2	12.6	12.0	13.6	14.8
15.6	15.0	13.2	12.2	14.6	15.0
15.4	14.8	12.4	11.8	14.2	15.4
16.0	14.6	12.6	11.6	14.0	15.4

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.12 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT Ph = 7.0

CONDUCTIVITY (λ) = 1.44 10^{-1} ohm^{01} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	18.14	18.18	18.15	18.17	18.14	18.20	
I(amp)	3.05	3.06	3.05	3.06	3.05	3.06	$\times 10^{-3}$
R(ohm)	5.95	5.94	5.95	5.94	5.95	5.95	$\times 10^{3}$
l(m)	8.56	8.56	8.57	8.56	8.56	8.56	$\times 10^{-2}$
E(volt m^{-1})	2.12	2.13	2.12	2.13	2.12	2.13	$\times 10^{2}$

18.0	13.8	11.6	12.0	14.2	14.6
17.6	13.6	11.8	11.2	14.0	14.8
17.4	14.0	12.2	11.4	14.2	14.4
17.8	14.2	12.2	11.0	13.8	15.0
18.2	13.6	12.0	11.6	13.6	14.8
18.0	13.4	11.8	11.8	14.4	14.6
17.6	13.8	11.4	11.8	13.8	15.2
17.2	13.2	11.6	11.4	14.0	15.4
18.2	13.6	12.0	11.4	14.2	15.0
17.8	13.2	11.4	11.6	14.6	15.4
17.2	13.4	11.6	11.2	14.2	14.8
17.6	14.0	12.0	11.2	13.8	15.2
17.4	13.8	11.8	11.0	13.8	14.6
17.4	14.2	12.2	12.0	14.0	15.0
17.8	13.4	11.4	11.6	14.2	14.8
17.6	13.6	11.8	11.8	13.6	15.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.13 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = $1.58\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	15.18	16.24	16.31	16.29	16.25	16.28	
I(amp)	2.80	3.0	3.01	3.01	3.0	3.01	$x10^{-3}$
R(ohm)	5.42	5.41	5.42	5.41	5.42	5.41	$x10^{3}$
l(m)	8.57	8.55	8.56	8.55	8.56	8.55	$x10^{-2}$
E(volt m^{-1})	1.77	1.90	1.91	1.91	1.90	1.91	$x10^{2}$

18.8	16.2	14.2	12.6	13.4	16.2
19.0	16.6	14.4	12.4	14.6	15.4
18.4	16.4	14.0	12.0	14.8	15.6
17.6	16.4	14.6	12.6	15.2	15.6
17.8	16.0	13.8	12.8	13.8	16.0
17.4	15.6	13.4	12.4	15.0	15.8
18.0	15.8	14.0	12.2	14.6	16.2
17.6	16.0	14.2	12.6	13.0	15.4
18.4	15.4	13.6	12.2	13.6	14.8
18.8	15.8	13.8	12.0	13.2	16.0
17.6	16.2	13.8	12.6	14.8	15.4
17.2	15.6	14.2	12.4	14.8	15.8
17.8	15.6	14.6	12.8	15.0	15.4
17.6	16.0	13.6	12.0	15.2	15.2
17.4	16.2	14.4	12.4	13.4	16.2
18.0	16.0	13.8	12.2	13.2	15.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.14 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = $1.58\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	17.23	17.28	16.85	16.91	16.94	17.26	
I(amp)	3.18	3.19	3.11	3.12	3.13	3.18	x10^{-3}
R(ohm)	5.42	5.42	5.42	5.42	5.41	5.43	x10^{3}
l(m)	8.56	8.56	8.56	8.56	8.55	8.58	x10^{-2}
E(volt m^{-1})	2.01	2.01	1.97	1.97	1.98	2.01	x10^{2}
	17.8	16.4	13.6	13.2	16.0	17.2	
	18.4	16.0	14.0	13.6	16.4	16.6	
	18.2	15.8	14.2	13.0	16.0	16.8	
	17.8	16.4	13.6	12.8	15.8	16.6	
	18.6	16.4	13.8	13.4	16.6	16.4	
	18.2	16.2	14.2	13.6	17.2	16.0	
	17.6	15.6	13.6	12.8	17.0	16.8	
	17.4	15.8	13.6	12.6	16.8	16.2	
	17.6	16.0	13.8	13.4	17.0	16.4	
	18.2	16.2	13.4	13.0	16.6	17.0	
	17.4	15.6	14.2	12.6	16.4	17.4	
	18.6	16.0	14.0	12.4	16.8	16.6	
	17.6	16.2	14.2	12.8	16.6	16.2	
	18.4	16.4	14.4	13.0	16.0	16.0	
	17.8	16.6	13.6	13.4	16.8	16.0	
	18.4	16.8	13.8	12.4	16.0	16.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.15 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = $1.58\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	16.94	16.97	17.06	17.09	17.08	17.12	
I(amp)	3.13	3.13	3.15	3.15	3.15	3.16	x10^{-3}
R(ohm)	5.41	5.42	5.42	5.43	5.42	5.42	x10^{3}
l(m)	8.55	8.57	8.56	8.57	8.57	8.56	x10^{-2}
E(volt m-1)	1.98	1.98	1.99	1.99	1.99	2.0	x10^{2}
	16.2	15.4	12.6	11.6	14.6	15.2	
	16.0	15.0	12.8	11.8	14.0	15.6	
	16.0	15.2	13.2	12.2	14.4	15.4	
	15.6	14.8	13.0	12.0	13.8	16.2	
	15.4	14.6	12.0	11.6	13.6	15.8	
	15.8	15.0	12.4	11.8	14.2	15.6	
	15.6	14.2	12.8	12.0	13.8	16.0	
	16.2	14.4	13.2	11.4	14.6	15.8	
	15.8	14.6	13.0	12.0	13.4	15.4	
	15.8	15.4	12.6	11.4	13.6	15.2	
	16.2	14.8	13.2	11.8	14.0	16.2	
	16.0	14.2	12.6	12.2	13.0	16.0	
	15.4	15.2	12.4	11.6	13.6	15.6	
	15.6	14.4	13.0	11.6	14.4	15.4	
	15.8	14.6	12.4	11.8	14.2	15.2	
	15.6	14.2	12.6	11.6	13.4	15.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.16 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = 1.58 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	17.04	16.98	16.95	16.97	16.93	16.98	
I(amp)	3.14	3.13	3.12	3.13	31.2	3.13	$x10^{-3}$
R(ohm)	5.43	5.42	5.43	5.42	5.43	5.42	$x10^{3}$
l(m)	8.57	8.57	8.58	8.57	8.57	8.57	$x10^{-2}$
E(volt m^{-1})	1.99	1.98	1,97	1,98	1,97	1,98	$x10^{2}$
	17.4	14.6	13.2	11.6	13.8	15.2	
	17.6	15.4	13.0	12.4	14.4	14.6	
	18.2	15.0	12.6	12.6	13.6	14.8	
	18.0	14.4	12.4	11.8	14.6	15.0	
	17.6	15.2	12.8	11.6	14.0	14.6	
	17.8	14.8	13.0	12.0	13.8	14.2	
	17.2	15.0	12.6	12.2	13.4	15.4	
	18.0	14.2	12.8	11.4	14.0	15.2	
	18.2	14.0	13.0	11.0	14.4	14.4	
	17.2	14.6	12.4	11.8	13.8	14.8	
	17.4	15.2	12.8	11.2	14.2	15.0	
	17.8	14.4	12.6	11.2	14.4	15.4	
	18.0	14.2	13.2	11.4	13.4	15.0	
	17.6	14.6	13.4	12.2	14.6	15.2	
	18.2	14.8	12.8	12.0	14.2	14.4	
	17.8	14.4	12.4	11.6	13.6	14.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.17 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.2

CONDUCTIVITY (λ) = 1.61 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) =28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	16.89	16.94	16.98	17.05	17.06	17.08	
I(amp)	3.18	3.19	3.20	3.21	3.21	3.21	x10^{-3}
R(ohm)	5.31	5.31	5.31	5.31	5.31	5.32	x10^{3}
l(m)	8.55	8.55	8.54	8.55	8.55	8.57	x10^{-2}
E(volt m^{-1})	1.98	1.98	1.99	1.99	1.99	1.99	x10^{2}

15.6	14.8	13.4	12.2	14.0	14.6
15.4	14.4	13.2	12.0	13.6	14.8
16.2	15.0	13.6	11.6	13.8	15.2
16.0	15.2	13.0	11.8	13.0	14.4
15.6	14.8	14.2	12.4	13.4	14.8
15.8	14.6	13.0	11.4	13.4	14.8
16.4	14.0	14.2	11.8	14.0	15.0
16.0	14.4	13.6	12.0	13.2	14.4
15.8	14.2	14.0	11.6	13.4	14.8
15.0	14.6	13.2	11.4	13.0	14.4
15.0	14.8	13.8	12.0	13.2	14.2
15.4	14.4	12.8	12.0	13.2	14.0
15.2	15.0	13.4	11.8	14.0	14.6
15.4	14.0	12.8	11.4	13.8	14.2
15.6	15.2	13.2	11.6	13.8	14.6
15.2	14.2	13.0	11.8	13.6	14.0

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.18 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.2

CONDUCTIVITY (λ) = 1.61 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	16.97	17.02	17.05	17.08	17.07	17.15	
I(amp)	3.19	3.20	3.21	3.21	3.21	3.23	x10^{-3}
R(ohm)	5.32	5.32	5.31	5.32	5.32	5.31	x10^{3}
l(m)	8.56	8.56	8.55	8.57	8.56	8.55	x10^{-2}
E(volt m^{-1})	1.98	1.99	1.99	1.99	1.99	2.01	x10^{2}
	17.2	15.6	13.8	13.2	16.2	16.4	
	16.4	15.8	13.4	12.6	15.8	17.0	
	17.0	16.2	13.4	12.8	15.2	16.6	
	17.2	16.0	13.6	13.0	16.0	16.8	
	16.8	15.4	14.0	13.4	15.8	16.2	
	16.0	16.2	13.0	12.2	16.2	16.0	
	16.2	15.6	13.6	12.0	15.4	16.8	
	16.0	16.0	13.2	12.2	15.6	16.0	
	16.4	15.4	14.2	13.0	15.2	15.8	
	15.8	15.2	14.0	12.0	15.6	16.2	
	15.8	15.8	13.2	12.8	15.2	15.8	
	17.0	15.0	13.8	13.2	15.6	16.0	
	16.6	15.0	14.2	12.4	15.4	16.4	
	16.8	15.6	13.2	12.6	15.8	16.2	
	16.4	15.2	14.0	12.2	15.2	16.6	
	16.2	15.6	13.4	12.4	16.0	16.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.19 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.2

CONDUCTIVITY (λ) = $1.61\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	10^{-2}
V(volt)	17.09	17.12	17.11	17.15	16.86	16.95	
I(amp)	3.21	3.22	3.22	3.23	3.17	3.19	10^{-3}
R(ohm)	5.32	5.32	5.31	5.31	5.32	5.31	10^{3}
l(m)	8.57	8.56	8.56	8.55	8.56	8.55	10^{-2}
E(volt m^{-1})	1.99	2.0	2.0	2.01	1.97	1.98	10^{2}
	15.6	14.8	12.2	11.8	13.8	15.2	
	15.4	14.2	12.0	12.2	14.2	14.8	
	15.0	14.0	12.2	12.0	14.2	14.6	
	14.8	14.4	12.4	11.6	13.6	15.2	
	14.6	14.6	11.8	12.0	14.0	15.0	
	15.2	14.2	11.8	12.4	14.4	15.4	
	15.6	14.0	12.4	11.8	13.4	15.6	
	15.0	15.0	12.8	11.6	13.8	15.2	
	14.6	14.4	12.6	11.4	13.6	14.8	
	15.2	13.8	12.2	11.6	13.4	15.0	
	14.8	13.8	12.8	11.2	13.6	15.6	
	15.6	14.2	12.0	12.0	13.2	15.4	
	14.8	14.0	12.0	11.8	14.2	15.2	
	15.2	14.6	12.4	11.2	14.0	15.0	
	14.6	14.8	12.6	12.4	13.8	14.6	
	15.2	13.8	12.2	11.4	13.2	14.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.20 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.2

CONDUCTIVITY (λ) = $1.61\ 10^{-1}$ $\text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	16.93	16.96	16.88	16.91	16.92	16.94	
I(amp)	3.18	3.19	3.17	3.18	3.18	3.19	$\times 10^{-3}$
R(ohm)	5.32	5.32	5.32	5.32	5.32	5.31	$\times 10^{3}$
l(m)	8.57	8.56	8.57	8.56	8.57	8.55	$\times 10^{-2}$
E(volt m^{-1})	1.98	1.98	1.97	1.98	1.98	1.98	$\times 10^{2}$
	17.2	15.6	13.8	12.4	13.4	14.2	
	17.8	14.8	13.4	11.8	12.8	14.6	
	17.2	14.4	14.0	11.8	13.0	15.2	
	17.6	13.6	12.2	12.0	14.2	15.0	
	17.0	15.2	12.8	11.6	14.0	14.8	
	18.0	14.2	13.2	12.0	13.8	15.0	
	18.2	15.4	12.6	12.2	13.6	14.4	
	17.4	14.8	12.0	11.4	13.2	14.2	
	17.6	14.6	12.8	11.2	13.8	14.2	
	17.4	14.2	12.0	11.6	13.2	14.8	
	18.0	13.8	12.2	11.8	13.4	14.8	
	17.8	13.6	12.6	12.2	13.6	14.4	
	17.6	14.8	12.4	11.2	13.0	14.6	
	18.2	15.0	13.2	11.0	13.4	14.6	
	17.2	15.6	13.4	11.0	13.6	14.8	
	17.8	15.0	12.4	11.2	13.8	15.0	

TIME (SEC) TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.21 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.9

CONDUCTIVITY (λ) = $1.61\ 10^{-1}\ \text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \text{m}^{2}$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVEISION SCREEN (X) = $28.0\ 10^{-2}$ m

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	10^{-2}
V(volt)	17.06	17.10	17.08	17.11	17.10	17.15	
I(amp)	3.22	3.23	3.22	3.23	3.23	3.24	$\times10^{-3}$
R(ohm)	5.30	5.30	5.30	5.30	5.30	5.30	$\times10^{3}$
l(m)	8.53	8.52	8.54	8.53	8.52	8.52	$\times10^{-2}$
E(volt m^{-1}	2.0	2.01	2.0	2.01	2.01	2.01	$\times10^{2}$
	15.2	14.6	13.0	12.4	13.8	14.2	
	15.6	13.8	13.4	12.0	13.2	14.6	
	15½4	14.0	13.2	12.4	13.4	15.0	
	14.8	14.0	13.0	11.8	13.0	14.8	
	14.6	14.2	12.6	11.2	13.2	15.2	
	15.0	14.4	12.8	11.6	13.8	14.2	
	15.6	13.6	13.4	11.8	14.0	14.4	
	14.8	13.8	13.0	12.2	14.2	14.8	
	15.0	14.2	12.6	11.2	13.4	14.6	
	15.4	13.6	12.8	11.6	13.6	15.2	
	14.8	14.6	13.2	11.4	13.2	14.8	
	15.6	14.4	13.4	12.2	13.8	14.4	
	15.2	13.6	12.8	12.0	13.0	14.6	
	15.0	14.0	13.2	11.6	13.0	14.2	
	14.6	13.8	12.6	12.4	13.2	15.0	
	15.2	13.4	13.0	11.8	14.0	14.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE THE TELEVISION SCREEN

TABLE C.22 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.9

CONDUCTIVITY (λ) = $1.61\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	17.07	17.13	17.05	17.11	17.13	17.08	
I(amp)	3.22	3.23	3.22	3.23	3.23	3.22	x10^{-3}
R(ohm)	5.30	5.30	5.30	5.30	5.30	5.30	x10^{3}
l(m)	8.54	8.54	8.53	8.53	8.54	8.54	x10^{-2}
E(volt m^{-1})	2.0	2.01	2.0	2.01	2.01	2.0	x10^{2}
	15.4	14.4	13.6	13.0	15.0	16.4	
	15.0	14.8	14.0	12.8	15.4	16.0	
	15.2	15.0	13.8	12.6	15.6	16.0	
	15.8	14.6	13.4	13.2	16.0	16.2	
	16.2	14.4	13.2	12.2	15.4	16.4	
	16.0	14.0	14.0	12.2	15.8	16.2	
	15.6	14.2	13.6	12.6	15.0	16.6	
	15.4	14.8	13.2	12.4	15.2	16.8	
	15.0	14.4	13.8	12.8	16.0	16.0	
	15.8	14.2	13.2	12.0	15.6	16.4	
	16.2	14.6	13.6	12.0	15.6	16.8	
	15.4	14.8	13½8	12.2	15.8	16.2	
	16.0	14.0	13.4	12.4	15.2	16.8	
	15.0	14.8	13.4	12.8	15.8	16.6	
	15.2	14.0	14.0	12.0	15.6	16.0	
	15.2	15.0	13.6	12.6	15.0	16.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.23 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.9

CONDUCTIVITY (λ) = $1.61\ 10^{-1}$ $ohm^{-1}m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	17.01	16.98	16.95	16.99	16.91	16.96	
I(amp)	3.21	3.20	3.19	3.20	3.19	3.20	$x10^{-3}$
R(ohm)	5.30	5.31	5.31	5.31	5.30	5.30	$x10^{3}$
l(m)	8.53	8.54	8.55	8.55	8.53	8.53	$x10^{-2}$
E(volt m^{-1})	1.99	1.99	1.98	1.99	1.98	1.99	$x10^{2}$
	15.2	14.6	12.4	11.6	13.4	14.6	
	15.0	15.2	11.8	12.0	13.0	14.8	
	15.2	14.8	11.6	11.4	13.0	15.2	
	14.6	14.8	12.0	11.2	13.8	14.8	
	15.2	14.4	11.6	11.6	14.0	14.4	
	14.8	14.0	11.6	11.0	14.2	14.2	
	15.2	13.8	11.8	11.0	14.0	15.0	
	14.6	14.4	12.2	11.4	13.6	15.2	
	14.2	13.6	11.8	11.2	13.2	14.2	
	14.0	13.8	11.6	11.6	13.8	14.6	
	14.8	14.2	12.2	12.0	13.4	14.8	
	14.2	14.0	12.0	11.8	13.6	15.0	
	15.0	14.0	11.8	11.4	13.8	14.2	
	15.0	13.6	12.0	11.8	13.2	14.6	
	14.6	13.4	11.6	11.4	13.4	14.4	
	14.4	13.6	11.8	11.0	13.8	14.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.24 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.9

CONDUCTIVITY (λ) = $1.61\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	17.02	17.06	16.94	16.97	17.04	17.09	
I(amp)	3.21	3.22	3.19	3.20	3.21	3.22	x10^{-3}
R(ohm)	5.30	5.30	5.31	5.30	5.31	5.31	x10^{3}
l(m)	8.54	8.53	8.55	8.54	8.55	8.55	x10^{-2}
E(volt m^{-1})	1.99	2.0	1.98	1.99	1.99	2.0	x10^{2}
	16.8	14.4	12.8	11.6	13.4	14.8	
	17.2	14.2	13.0	11.8	13.2	14.2	
	17.4	13.8	13.2	11.2	13.0	14.0	
	17.0	13.6	12.6	11.4	13.6	14.2	
	17.4	13.2	12.0	11.6	13.6	14.0	
	16.8	14.8	12.0	11.0	13.4	14.2	
	16.6	14.2	12.8	11.4	12.8	14.8	
	16.6	14.0	12.6	11.6	13.2	13.8	
	16.4	13.2	12.4	11.0	13.2	14.0	
	17.0	13.8	12.0	11.2	13.0	13.8	
	16.8	13.6	12.2	11.2	12.6	13.6	
	16.6	14.0	12.2	11.8	13.2	14.2	
	17.2	14.4	11.8	11.6	13.4	14.4	
	15.8	14.4	11.6	11.8	13.2	14.8	
	15.6	13.2	12.0	12.0	12.8	14.8	
	15.8	14.6	11.8	12.0	13.0	14.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN.

TABLE C.25 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = $1.68\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	16.96	16.98	16.95	16.99	16.94	16.96	
I(amp)	3.33	3.33	3.33	3.33	3.32	3.33	$x10^{-3}$
R(ohm)	5.10	5.10	5.09	5.10	5.10	5.10	$x10^{3}$
l(m)	8.56	8.57	8.55	8.57	8.57	8.56	$x10^{-2}$
E(volt m^{-1})	1.98	1.98	1.98	1.98	1.98	1.98	$x10^{2}$
	15.0	14.2	12.8	12.4	13.4	14.6	
	15.8	13.6	13.4	12.6	13.2	14.0	
	16.2	15.2	12.6	11.0	13.8	14.8	
	16.4	14.6	12.4	11.8	13.2	15.6	
	15.6	13.0	12.8	11.6	13.6	14.6	
	15.8	13.6	13.2	12.0	14.2	14.2	
	15.4	14.8	12.6	11.6	13.8	14.8	
	16.2	13.4	13.0	12.4	13.4	14.4	
	14.8	12.4	12.0	14.0	15.0		
	14.6	13.8	12.6	11.6	14.2	14.8	
	14.2	13.4	13.0	11.4	13.6	14.4	
	14.4	14.0	12.4	11.2	13.0	14.6	
	15.8	13.2	12.8	11.0	13.2	14.0	
	14.4	13.4	12.6	12.2	13.0	14.6	
	14.8	13.8	12.2	11.8	13.4	14.4	
	14.6	13.6	12.4	11.4	13.8	14.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.26 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = 1.68 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	16.93	16.97	16.94	16.99	16.95	16.98	
I(amp)	3.32	3.33	3.32	3.33	3.33	3.33	$x10^{-3}$
R(ohm)	5.10	5.10	5.10	5.10	5.09	5.10	$x10^{3}$
l(m)	8.57	8.56	8.57	8.57	8.55	8.57	$x10^{-2}$
E(volt m^{-1})	1.98	1.98	1.98	1.98	1.98	1.98	$x10^{2}$
	15.2	14.0	13.4	12.8	15.6	16.8	
	15.8	14.6	13.2	13.0	15.2	17.2	
	16.0	15.2	13.8	13.0	16.2	17.0	
	15.6	14.8	13.2	12.6	16.0	16.6	
	16.0	14.0	13.6	12.0	15.6	17.0	
	15.4	14.8	13.4	12.4	15.8	16.4	
	15.2	14.4	13.2	12.6	15.4	16.0	
	16.0	14.6	13.8	12.2	15.2	15.8	
	15.4	14.4	13.0	12.0	15.8	16.6	
	15.6	14.2	13.8	12.4	15.2	16.2	
	15.2	14.8	13.4	12.2	15.4	16.8	
	15.0	14.6	13.4	12.8	16.2	16.4	
	16.2	14.2	13.2	12.6	15.8	15.8	
	15.8	14.8	13.2	13.0	15.4	16.6	
	15.4	14.0	13.0	12.8	16.0	17.0	
	15.2	14.4	13.6	12.4	15.6	16.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVEISION SCREEN

TABLE C.27 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = $1.68\ 10^{-1}$ $ohm^{-1}\ m^{-1}$

CROSS-SECRIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ m^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	17.04	17.07	17.05	17.06	17.09	17.11	
I(amp)	3.34	3.35	3.34	3.35	3.35	3.36	$x10^{-3}$
R(ohm)	5.10	5.10	5.10	5.09	5.10	5.09	$x10^{3}$
l(m)	8.57	8.56	8.58	8.56	8.57	8.56	$x10^{-2}$
E(volt m^{-1})	1.99	1.99	1.99	1.99	1.99	2.0	$x10^{2}$

14.0	13.2	12.2	11.6	13.2	14.8
13.8	13.8	11.6	11.0	12.8	13.8
13.6	13.6	11.4	11.0	12.6	14.0
14.0	13.0	12.0	11.4	13.0	13.4
14.2	13.4	11.6	12.0	13.0	13.6
13.8	13.2	11.2	11.4	13.8	14.4
13.4	13.0	11.8	11.8	13.4	14.6
13.2	13.8	11.6	11.2	13.0	14.0
13.6	14.0	11.4	11.2	12.6	14.4
14.2	14.4	11.8	11.4	13.2	14.2
13.8	13.8	12.0	11.8	13.6	14.8
13.2	13.4	12 .2	11.2	12.8	14.0
13.2	13.0	11.4	11.6	12.6	14.6
13.6	13.6	11.6	11.4	13.2	14.2
13.8	13.2	11.8	11.0	12.8	13.8
13.4	13.2	11.20	11.4	13.4	13.6

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.28 ELECTROPHORESIS OF THE COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = $1.68\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	17.04	17.09	17.10	17.12	17.13	17.15	
I(amp)	3.34	3.35	3.35	3.36	3.36	3.36	$\times 10^{-3}$
R(ohm)	5.10	5.09	5.10	5.10	5.10	5.10	$\times 10^{3}$
l(m)	8.57	8.56	8.58	8.56	8.57	8.58	$\times 10^{-2}$
E(volt m^{-1})	1.99	2.0	1.99	2.0	2.0	2.0	$\times 10^{2}$
	16.6	14.0	11.8	11.6	12.8	14.6	
	15.8	13.6	12.2	11.0	13.0	14.0	
	16.0	13.2	12.0	11.2	12.4	13.6	
	15.8	13.8	11.6	11.2	12.0	13.2	
	16.2	13.0	11.6	11.0	11.8	13.6	
	16.0	14.2	11.2	11.4	11.6	13.0	
	15.6	13.2	11.4	10.8	12.0	14.0	
	15.4	13.0	11.2	10.6	11.4	13.8	
	15.6	13.8	12.0	11.0	11.6	13.4	
	15.2	13.6	11.8	11.4	12.4	14.2	
	16.2	13.0	12.2	10.8	11.8	13.8	
	16.0	14.0	11.8	10.8	11.4	13.4	
	15.2	13.4	11.0	10.6	12.0	13.4	
	15.4	13.6	11.4	11.0	12.0	13.2	
	15.4	13.2	11.2	11.2	11.6	13.8	
	15.6	13.4	11.6	11.6	11.4	13.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.29 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 2.7

CONDUCTIVITY (λ) = $2.58\ 10^{-1}\ \mathrm{ohm}^{-1}\ \mathrm{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \mathrm{m}^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m.

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$\times 10^{-2}$
V(volt)	16.52	16.55	16.56	16.58	16.51	16.54	
I(amp)	4.99	4.99	4.99	5.00	4.98	4.99	$\times 10^{-3}$
R(ohm)	3.31	3.31	3.32	3.32	3.32	3.31	$\times 10^{3}$
l(m)	8.54	8.56	8.56	8.56	8.55	8.55	$\times 10^{-2}$
E(volt m^{-1})	1.93	1.93	1.93	1.94	1.93	1.93	$\times 10^{2}$
	14.2	13.4	12.4	11.8	12.8	13.8	
	14.0	13.6	12.8	11.6	13.2	13.6	
	14.0	13.0	12.4	12.0	13.0	14.0	
	13.6	12.8	12.6	12.2	13.4	14.6	
	14.2	12.8	12.0	11.8	13.2	14.2	
	13.8	13.2	12.2	11.4	13.8	14.8	
	13.4	13.0	12.2	11.8	13.6	14.4	
	13.0	13.2	12.6	11.8	13.8	14.0	
	13.8	13.0	12.8	12.0	13.2	13.4	
	13.6	13.4	12.4	11.2	12.8	13.8	
	14.0	13.6	12.0	11.6	13.6	14.2	
	13.4	13.4	12.4	11.4	13.6	14.0	
	14.2	13.6	12.2	11.4	13.4	13.6	
	13.8	12.6	12.6	11.8	14.0	13.4	
	13.8	12.8	12.4	11.6	13.8	14.6	
	13.6	13.4	12.0	11.2	12.8	14.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.30 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 2.7

CONDUCTIVITY (λ) = $2.58\ 10^{-1}$ $\text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.25	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	16.52	16.56	16.53	16.58	16.54	16.57	
I(amp)	4.99	4.99	4.99	5.00	4.99	5.00	$\times 10^{-3}$
R(ohm)	3.31	3.32	3.31	3.32	3.31	3.31	$\times 10^{3}$
l(m)	8.54	8.56	8.55	8.56	8.55	8.55	$\times 10^{-2}$
E(volt m^{-1})	1.93	1.93	1.93	1.94	1.93	1.94	$\times 10^{2}$
	14.6	13.4	12.8	12.0	14.4	15.8	
	14.4	13.0	13.0	11.8	14.8	15.6	
	15.2	13.6	12.6	11.6	14.0	16.0	
	14.8	13.4	12.2	11.2	14.8	15.4	
	14.6	13.2	12.6	11.8	14.2	16.2	
	14.2	14.0	12.4	11.4	14.6	15.6	
	14.6	14.2	12.8	12.0	15.0	15.2	
	15.0	13.8	12.4	11.6	14.6	16.0	
	15.2	13.6	12.2	11.4	14.2	16.2	
	14.2	13.2	12.6	11.2	14.4	15.4	
	14.6	13.8	12.8	11.8	15.0	15.2	
	14.4	14.2	12.2	11.0	14.6	15.8	
	14.8	13.4	12.2	12.0	14.4	15.6	
	15.0	13.6	12.6	11.6	14.8	15.2	
	14.4	14.0	12.4	11.4	14.2	15.4	
	14.8	13.4	12.6	11.2	14.4	15.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.31 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 2.7

CONDUCTIVITY (λ) = 2.58 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	16.55	16.59	16.52	16.54	16.56	16.62	
I(amp)	4.99	5.00	4.99	4.99	4.99	5.00	$x10^{-3}$
R(ohm)	3.31	3.32	3.31	3.31	3.32	3.32	$x10^{3}$
l(m)	8.55	8.56	8.54	8.55	8.56	8.57	$x10^{-2}$
E(volt m^{-1})	1.93	1.94	1.93	1.93	1.93	1.94	$x10^{2}$
	13.8	12.6	11.2	11.0	12.4	13.6	
	13.4	12.0	11.6	10.4	12.6	13.8	
	12.8	12.4	11.2	10.2	11.8	14.0	
	13.0	13.2	11.8	10.6	11.6	13.4	
	12.8	12.8	11.0	10.4	12.0	13.4	
	13.2	12.6	10.8	10.0	12.4	12.8	
	12.6	12.2	10.6	11.2	12.2	12.6	
	12.4	13.0	11.2	10.8	11.8	12.8	
	12.6	13.2	11.4	11.2	12.6	12.4	
	13.0	12.4	11.4	11.6	12.2	13.6	
	13.4	12.8	11.6	10.8	12.0	12.4	
	12.4	12.2	10.8	10.2	11.6	13.8	
	13.2	12.6	10.8	10.4	11.8	12.6	
	13.8	12.0	11.0	10.6	12.0	12.6	
	12.4	13.0	10.6	10.4	12.0	12.2	
	12.6	12.6	10.6	10.4	12.4	12.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.32 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 2.7

CONDUCTIVITY (λ) = $2.58\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	16.63	16.65	16.62	16.66	16.56	16.59	
I(amp)	5.00	5.01	5.00	5.01	4.99	5.00	x10^{-3}
R(ohm)	3.33	3.32	3.32	3.33	3.32	3.32	x10^{3}
l(m)	8.58	8.57	8.58	8.58	8.56	8.56	x10^{-2}
E(volt m^{-1}	1.94	1.94	1.94	1.94	1.93	1.94	x10^{2}
	15.8	14.2	11.4	10.6	12.4	12.8	
	16.0	13.8	11.0	10.2	12.0	13.4	
	15.4	13.6	11.6	10.4	12.0	13.6	
	15.0	13.4	11.2	10.2	11.8	13.6	
	15.4	13.0	11.0	10.8	11.6	13.0	
	15.6	13.8	11.8	10.6	11.8	13.2	
	15.2	13.4	11.4	11.0	12.4	13.4	
	15.6	13.2	11.4	10.4	11.4	13.0	
	15.0	14.0	11.8	11.0	11.6	13.8	
	15.8	14.0	11.6	10.6	11.6	13.6	
	15.4	13.2	10.8	10.6	11.2	13.0	
	15.4	14.2	10.8	10.2	12.0	13.0	
	16.0	13.6	11.2	11.0	12.2	13.2	
	15.8	13.2	11.2	10.8	12.4	13.4	
	15.6	13.4	11.0	10.8	11.8	13.6	
	15.4	13.0	11.4	10.6	12.0	13.6	

TIME (SEC) TAKEN TO TRAVELL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.33 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 1.9

CONDUCTIVITY (λ) = 7.40 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	10.92	10.95	10.96	10.98	10.95	10.97	
I(amp)	9.41	9.44	9.44	9.45	9.44	9.45	$x10^{-3}$
R(ohm)	1.16	1.16	1.16	1.16	1.16	1.16	$x10^{3}$
l(m)	8.59	8.58	8.59	8.60	8.58	8.59	$x10^{-2}$
E(volt m^{-1}	1.27	1.28	1.28	1.28	1.28	1.28	$x10^{2}$

18.0	16.6	15.8	14.6	14.6	16.2
18.2	17.2	15.4	14.6	14.8	16.6
18.4	16.8	16.2	14.6	15.2	16.4
17.8	17.0	16.0	14.0	15.2	16.4
18.0	16.6	15.8	13.6	14.6	16.0
17.6	16.4	15.4	13.8	15.4	17.2
17.2	16.8	15.6	13.8	14.8	16.8
17.4	17.4	15.6	14.2	14.8	17.0
17.8	16.8	15.2	13.6	15.2	17.4
17.4	16.6	15.4	13.4	15.6	16.8
18.2	16.2	15.8	13.4	15.6	16.6
17.6	16.4	15.8	14.8	14.4	16.0
18.4	16.8	16.2	14.6	14.8	16.2
17.4	16.6	15.6	14.4	14.4	16.2
17.6	17.0	16.0	13.6	15.2	16.6
17.6	16.6	15.4	13.8	15.4	16.4

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.34 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 1.9

CONDUCTIVITY (λ) = 7.40 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	10.94	10.96	10.93	10.97	10.98	10.99	
I(amp)	9.42	9.44	9.42	9.45	9.46	9.47	x10^{-3}
R(ohm)	1.16	1.16	1.16	1.16	1.16	1.16	x10^{3}
l(m)	8.59	8.59	8.59	8.59	8.59	8.59	x10^{-2}
E(volt m^{-1}	1.27	1.28	1.27	1.28	1.28	1.28	x10^{2}
	16.8	15.8	15.4	13.8	14.8	15.4	
	16.6	16.2	14.8	14.2	15.2	15.8	
	17.2	16.6	14.6	14.6	14.6	16.6	
	17.4	16.6	15.2	14.6	14.6	15.8	
	16.8	17.0	15.2	13.8	15.4	16.4	
	17.2	16.0	14.6	14.0	15.4	15.4	
	17.8	15.6	14.4	14.2	15.8	16.6	
	17.8	15.6	15.4	14.0	16.2	16.8	
	16.6	15.4	14.8	13.6	16.0	17.2	
	17.2	15.4	14.4	13.6	15.8	17.0	
	16.4	17.2	14.8	14.6	15.6	16.8	
	17.8	17.0	15.6	14.8	14.8	16.4	
	18.0	16.0	15.4	14.6	15.2	16.8	
	17.4	16.2	14.8	13.8	15.4	17.2	
	16.4	16.4	14.6	14.0	15.2	17.4	
	17.4	15.8	14.6	14.0	15.6	17.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.35 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 1.9

CONDUCTIVITY (λ) = $7.40\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	10.89	10.90	10.87	10.91	10.84	10.87	
I(amp)	9.39	9.40	9.38	9.41	9.34	9.28	x10^{-3}
R(ohm)	1.16	1.16	1.16	1.16	1.16	1.16	x10^{3}
l(m)	8.58	8.58	8.58	8.58	8.59	8.58	x10^{-2}
E(volt m^{-1})	1.27	1.27	1.27	1.27	1.26	1.27	x10^{2}
	17.4	16.8	15.4	15.2	15.4	15.8	
	17.6	16.8	15.2	14.8	15.2	15.6	
	17.0	16.4	16.2	15.6	15.2	15.6	
	17.2	16.6	15.8	14.6	14.8	15.2	
	17.6	16.4	16.4	15.4	14.2	16.4	
	17.6	17.6	15.0	15.4	15.2	16.6	
	17.8	17.4	15.6	14.8	14.6	15.8	
	17.0	16.2	16.4	14.6	14.2	16.6	
	17.2	16.2	16.0	14.8	14.8	16.8	
	17.2	16.0	15.4	14.4	15.4	15.2	
	17.8	16.8	15.6	14.2	14.6	15.4	
	17.4	16.2	15.2	15.6	14.4	16.6	
	17.8	16.4	15.8	15.2	14.4	16.2	
	17.2	16.6	16.0	14.0	14.8	16.2	
	17.4	17.6	16.4	14.2	14.2	15.8	
	17.4	17.2	16.2	14.0	14.4	16.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE C.36 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 1.9

CONDUCTIVITY (λ) = $7.40\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{-2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	10.86	10.88	10.91	10.89	10.87	10.91	
I(amp)	9.36	9.38	9.41	9.39	9.38	9.41	x10^{-3}
R(ohm)	1.16	1.16	1.16	1.16	1.16	1.16	x10^{3}
l(m)	8.59	8.58	8.58	8.58	8.58	8.58	x10^{-2}
E(volt m^{-1})	1.26	1.27	1.27	1.27	1.27	1.27	x10^{2}
	17.2	15.4	14.6	13.6	15.4	16.2	
	16.6	16.8	14.8	13.8	15.6	16.0	
	16.6	15.2	15.2	14.2	15.2	15.4	
	17.0	15.2	15.2	14.4	14.8	15.8	
	16.8	15.6	14.4	14.6	14.6	16.4	
	16.8	15.4	15.6	13.8	15.4	16.0	
	17.6	16.6	15.4	13.4	14.8	16.2	
	17.4	16.2	14.8	13.4	14.4	15.6	
	17.6	15.8	15.6	13.2	14.8	16.4	
	17.4	15.6	15.4	14.2	14.6	15.6	
	17.4	15.8	14.4	13.2	15.6	15.6	
	16.8	16.0	14.8	14.0	15.6	15.4	
	17.2	16.2	14.8	14.0	14.4	15.2	
	17.0	16.0	14.2	13.6	15.2	15.2	
	16.8	16.4	14.6	13.4	14.6	15.8	
	17.2	16.4	14.6	14.2	14.4	16.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

ELECTROPHORESIS OF COLLIERY WASTE-WATER USING H_2SO_4

APPENDIX D

TABLE D.1 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.8

CONDUCTIVITY (λ) = 1.34 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	20.51	20.50	20.53	20.55	20.53	20.57	
I(amp)	3.19	3.19	3.20	3.20	3.19	3.20	x10^{-3}
R(ohm)	6.43	6.43	6.42	6.42	6.44	6.43	x10^{3}
l(m)	8.62	8.61	8.60	8.61	8.62	8.61	x10^{-2}
E(volt m^{-1})	2.38	2.38	2.39	2.39	2.38	2.39	x10^{2}
	17.2	16.2	15.6	14.8	15.6	16.2	
	16.8	15.8	15.0	15.0	15.8	16.0	
	17.0	15.6	15.0	14.2	15.4	16.0	
	16.6	15.4	15.2	14.0	16.0	15.6	
	16.2	16.4	15.4	14.0	16.4	15.8	
	17.4	16.0	15.6	14.4	15.8	16.4	
	17.6	15.8	15.8	14.6	16.2	16.6	
	16.4	15.2	14.8	14.2	15.6	15.8	
	16.6	16.0	15.4	14.4	15.4	16.6	
	16.8	16.4	15.2	14.6	15.6	16.8	
	17.2	15.2	14.6	14.8	16.0	16.6	
	17.0	15.4	14.8	14.2	15.2	16.4	
	16.4	16.0	15.2	14.2	15.2	16.2	
	16.2	15.4	15.6	15.2	15.4	15.6	
	16.6	15.6	14.8	14.8	15.8	16.2	
	16.4	15.4	14.8	15.0	15.4	16.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.2 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.8

CONDUCTIVITY (λ) = $1.34\ 10^{-1}$ $ohm^{-1}\ m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ m^{2}$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	20.55	20.52	20.54	20.56	20.57	20.58	
I(amp)	3.19	3.19	3.19	3.20	3.20	3.20	$x10^{-3}$
R(ohm)	6.44	6.43	6.44	6.43	6.43	6.44	$x10^{3}$
l(m)	8.63	8.62	8.63	8.61	8.61	8.61	$x10^{-2}$
E(volt m^{-1})	2.38	2.38	2.38	2.39	2.39	2.39	$x10^{2}$
	18.2	16.8	15.2	15.0	15.6	16.8	
	17.8	17.2	15.8	14.6	15.4	16.4	
	17.6	17.0	16.0	14.4	16.2	17.2	
	18.0	16.6	16.2	15.2	16.0	17.0	
	17.6	17.2	15.6	14.2	16.6	16.6	
	18.2	16.4	15.4	14.8	15.8	17.6	
	17.4	16.2	15.4	14.2	16.4	17.4	
	17.0	16.6	15.2	14.4	16.6	17.4	
	17.4	17.0	15.6	14.8	15.8	16.6	
	17.2	16.8	16.0	15.0	15.4	16.4	
	18.0	16.8	15.8	14.2	16.0	17.0	
	17.8	16.4	16.2	14.6	15.6	16.8	
	17.2	16.6	15.8	15.2	16.2	17.4	
	17.4	16.2	16.4	14.4	15.8	16.4	
	17.6	16.4	16.0	14.0	16.0	17.2	
	17.8	16.4	15.4	14.0	16.4	17.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.3 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.8

CONDUCTIVITY (λ) = 1.34 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	20.52	20.54	20.56	20.55	20.53	20.54	
I(amp)	3.19	3.19	3.19	3.19	3.19	3.19	x10^{-3}
R(ohm)	6.43	6.44	6.45	6.44	6.44	6.44	x10^{3}
l(m)	8.62	8.63	8.64	8.63	8.62	8.63	x10^{-2}
E(volt m^{-1})	2.38	2.38	2.38	2.38	2.38	2.38	x10^{2}
	16.8	17.4	16.2	14.8	16.6	16.8	
	17.4	17.8	26.0	14.8	16.4	17.4	
	17.6	16.8	15.6	14.0	16.2	17.8	
	18.0	16.6	15.2	13.8	17.2	18.2	
	18.2	16.4	15.8	13.6	15.8	18.2	
	17.8	16.0	15.0	14.6	15.6	18.4	
	18.4	16.8	15.8	14.2	17.0	18.0	
	17.0	16.2	16.0	14.2	16.0	17.8	
	17.2	17.2	15.6	14.6	16.8	17.0	
	17.6	26.8	16.2	14.2	16.4	17.4	
	17.8	16.2	15.8	14.2	16.6	28.2	
	17.0	16.4	15.2	14.0	16.0	17.8	
	17.4	16.0	15.0	14.4	17.0	18.0	
	16.8	16.6	15.4	14.6	16.8	18.2	
	17.6	16.4	15.4	13.8	16.2	18.2	
	18.2	16.2	16.0	14.8	16.4	18.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.4 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 8.8

CONDUCTIVITY (λ) = $1.34\ 10^{-1}\ \text{ohm}^{-1}\ \text{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \text{m}^{2}$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE NEGATIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	20.55	20.57	20.52	20.54	20.54	20.55	
I(amp)	3.19	3.19	3.19	3.19	3.19	3.19	$x10^{-3}$
R(ohm)	6.44	6.45	6.43	6.44	6.44	6.44	$x10^{3}$
l(m)	8.63	8.64	8.62	8.63	8.62	8.63	$x10^{-2}$
E(volt m^{-1})	2.38	2.38	2.38	2.38	2.38	2.38	$x10^{2}$
	17.2	16.6	15.2	13.6	14.8	16.2	
	17.8	17.0	15.6	13.8	15.2	16.6	
	18.4	17.2	15.8	14.2	15.6	16.8	
	18.6	26.8	16.0	14.0	16.2	16.0	
	18.2	16.2	16.0	13.8	15.8	15.8	
	17.6	16.0	15.4	14.8	15.0	16.4	
	18.0	16.4	15.6	14.6	14.6	17.2	
	18.4	17.0	16.2	14.2	15.4	17.4	
	17.6	17.2	15.0	14.4	15.4	16.8	
	17.8	16.4	15.2	14.0	15.6	17.4	
	18.0	16.2	15.0	14.8	14.8	17.2	
	18.4	16.6	15.6	14.4	16.0	16.6	
	18.2	17.0	15.8	14.6	16.2	16.4	
	17.2	16.4	16.2	14.8	15.8	16.2	
	17.4	16.6	15.4	14.2	15.6	17.2	
	17.4	16.8	15.4	14.4	15.2	16.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.5 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.39\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	20.28	20.32	20.26	20.29	20.28	20.25	
I(amp)	3.28	3.29	3.28	3.28	3.28	3.27	x10^{-3}
R(ohm)	6.18	6.18	6.18	6.19	6.18	6.19	x10^{3}
l(m)	8.59	8.59	8.59	8.60	8.59	8.60	x10^{-2}
E(volt m^{-1})	2.36	2.37	2.36	2.36	2.36	2.35	x10^{2}
	15.2	14.4	14.0	13.4	14.0	15.6	
	15.0	14.0	14.2	12.8	14.6	15.8	
	14.6	13.8	13.8	12.4	15.2	16.2	
	14.2	13.6	13.6	13.0	14.6	16.4	
	14.6	14.2	14.2	12.6	14.8	14.8	
	15.2	14.0	13.2	12.8	15.0	15.4	
	14.8	13.4	13.4	12.2	14.4	15.0	
	14.4	13.8	14.0	13.6	14.2	15.8	
	14.6	14.6	13.2	12.2	14.6	16.0	
	14.8	14.2	13.0	12.6	15.0	16.2	
	15.4	13.6	13.6	13.0	14.4	15.6	
	15.2	13.4	13.4	12.8	14.8	15.4	
	14.4	14.4	13.2	12.8	14.2	15.2	
	15.0	13.8	13.8	12.4	15.2	16.4	
	15.4	14.2	14.2	12.6	14.8	15.6	
	14.8	14.6	13.6	12.4	14.4	15.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.6 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.39\ 10^{-1}\ ohm^{-1}\ m^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ m^2$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	20.26	20.27	20.29	20.30	20.24	20.25	
I(amp)	3.28	3.28	3.28	3.28	3.27	3.27	$\times 10^{-3}$
R(ohm)	6.18	6.18	6.19	6.19	6.19	6.19	$\times 10^{3}$
l(m)	8.59	8.60	8.60	8.60	8.60	8.60	$\times 10^{-2}$
E(volt m^{-1})	2.36	2.36	2.36	2.36	2.35	2.35	$\times 10^{2}$
	15.2	14.8	13.6	12.4	14.8	14.6	
	15.8	14.2	13.8	12.2	14.4	14.0	
	16.2	15.0	14.2	13.0	14.2	13.8	
	16.0	15.4	14.4	12.6	13.6	14.2	
	16.4	14.6	13.6	13.2	14.0	15.0	
	15.6	15.0	13.4	13.2	13.8	15.4	
	15.4	14.4	14.0	12.8	14.6	15.8	
	15.6	14.6	13.6	12.2	14.0	16.2	
	15.2	15.4	14.0	13.0	13.8	15.4	
	16.0	15.0	14.2	13.2	14.2	14.6	
	15.8	14.8	13.4	12.6	13.8	14.8	
	15.4	14.2	13.6	12.6	14.4	15.6	
	16.0	14.6	13.6	12.8	14.0	15.8	
	15.8	14.8	14.0	12.4	14.0	16.2	
	15.6	14.6	13.8	12.2	13.6	15.4	
	15.2	14.4	13.4	12.4	14.6	15.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.7 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.39\ 10^{-1}\ \mathrm{ohm}^{-1}\ \mathrm{m}^{-1}$

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}\ \mathrm{m}^{2}$

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}\ \mathrm{m}$

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	20.35	20.36	20.34	20.36	20.32	20.35	
I(amp)	3.29	3.29	3.29	3.29	3.29	3.29	$x10^{-3}$
R(ohm)	6.19	6.19	6.18	6.19	6.18	6.19	$x10^{3}$
l(m)	8.60	8.60	8.60	8.60	8.59	8.60	$x10^{-2}$
E(volt m-1)	2.37	2.37	2.37	2.37	2.37	2.37	$x10^{2}$
	14.8	13.8	13.2	13.6	14.2	14.8	
	15.4	14.2	13.0	12.8	14.6	14.6	
	15.2	14.4	13.0	13.0	14.0	14.2	
	14.8	14.0	13.6	13.2	13.8	15.0	
	14.6	13.6	13.8	12.6	13.6	15.4	
	15.0	14.0	13.4	12.4	14.4	14.4	
	14.8	14.2	13.2	12.8	14.2	15.6	
	14.4	14.8	13.6	13.2	14.8	15.8	
	15.4	14.6	14.0	12.2	14.4	15.6	
	14.6	14.8	14.2	12.0	14.0	15.0	
	15.0	14.4	13.6	12.4	14.2	14.8	
	14.6	14.6	13.4	12.2	13.8	14.4	
	14.4	14.4	13.0	12.6	14.6	15.2	
	15.2	13.8	13.2	12.4	14.8	15.2	
	15.2	14.0	13.8	12.4	13.6	14.6	
	14.8	13.6	13.4	12.8	14.4	14.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.8 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 7.0

CONDUCTIVITY (λ) = $1.39\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times10^{-2}$
V(volt)	20.35	20.39	20.37	20.38	20.35	20.38	
I(amp)	3.29	3.30	3.29	3.29	3.29	3.29	$\times10^{-3}$
R(ohm)	6.19	6.18	6.19	6.19	6.19	6.19	$\times10^{3}$
l(m)	8.60	8.59	8.61	8.61	8.60	8.61	$\times10^{-2}$
E(volt m^{-1})	2.37	2.37	2.37	2.37	2.37	2.37	$\times10^{2}$

14.6	14.6	13.4	12.2	14.2	14.8
14.8	14.6	13.6	12.0	14.6	14.2
15.2	14.4	13.2	11.8	14.2	14.2
15.4	15.2	13.0	12.4	15.0	14.6
15.0	13.8	13.2	13.0	14.4	15.0
14.4	14.2	12.8	12.8	15.2	15.6
15.6	14.0	12.6	11.6	14.8	15.4
15.2	14.4	13.4	12.0	14.6	15.8
15.0	13.8	13.8	11.8	14.4	16.2
14.8	13.6	13.6	12.2	15.2	16.4
14.4	14.0	13.0	12.2	15.0	16.4
15.4	14.4	12.8	12.0	14.8	15.6
15.6	13.6	12.4	11.6	14.4	15.8
14.6	13.4	13.2	12.4	14.6	16.2
15.2	13.8	13.4	12.4	14.6	16.0
15.4	13.4	13.6	11.6	14.8	16.0

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.9. ELECTROPHORESIS OF THE COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ)	= 1.50 10^{-1} ohm^{-1} m^{-1}
CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A)	= 1.0 10^{-4} m^{2}
DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X)	= 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$\times 10^{-2}$
V(volt)	19.17	19.15	19.11	19.09	19.10	19.11	
I(amp)	3.34	3.34	3.33	3.33	3.33	3.33	$\times 10^{-3}$
R(ohm)	5.74	5.73	5.74	5.73	5.74	5.74	$\times 10^{3}$
1(m)	8.61	8.60	8.61	8.60	8.60	8.61	$\times 10^{-2}$
E(volt m^{-1})	2.23	2.23	2.22	2.22	2.22	2.22	$\times 10^{2}$
	14.4	14.0	12.8	12.0	12.8	13.2	
	14.8	14.2	12.2	11.8	13.4	13.8	
	15.0	14.0	12.2	11.4	13.2	14.2	
	15.2	13.8	12.6	12.2	13.0	14.0	
	15.0	13.6	12.8	11.6	12.8	14.4	
	14.6	14.0	12.0	11.0	12.6	14.2	
	14.6	13.4	12.4	11.4	13.2	13.6	
	14.8	13.4	12.4	11.8	13.0	13.8	
	15.4	13.6	13.0	11.8	13.4	13.4	
	14.4	13.2	12.6	11.0	12.6	14.4	
	14.6	12.8	12.0	11.6	13.0	14.8	
	15.4	13.0	12.4	12.0	13.4	13.6	
	15.0	13.6	12.2	11.4	12.4	13.2	
	14.8	13.2	12.8	11.2	12.6	14.8	
	15.2	13.0	13.0	11.2	12.4	14.0	
	15.2	13.8	13.0	11.0	12.8	13.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.10 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = 1.50 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	19.08	19.12	19.07	19.11	10.09	19.12	
I(amp)	3.33	3.33	3.32	3.33	3.33	3.33	x10^{-3}
R(ohm)	5.73	5.74	5.74	5.74	5.73	5.74	x10^{3}
l(m)	8.59	8.61	8.62	8.61	8.60	8.61	x10^{-2}
E(volt m^{-1})	2.22	2.22	2.21	2.22	2.22	2.22	x10^{2}
	14.8	14.0	12.8	12.4	12.8	13.6	
	15.2	13.6	13.4	11.8	13.2	13.8	
	15.2	13.6	13.0	12.0	13.0	14.0	
	14.6	13.4	12.6	11.4	12.6	14.4	
	15.0	13.8	12.4	11.6	13.4	13.4	
	14.8	14.2	12.2	11.8	13.4	14.2	
	14.4	14.4	13.2	12.2	13.6	14.6	
	14.2	13.8	12.0	12.0	13.2	14.2	
	14.4	13.6	12.6	11.8	13.0	14.6	
	14.8	13.4	13.2	11.6	12.8	14.0	
	15.0	13.4	12.4	12.2	12.6	14.2	
	14.8	14.0	12.8	11.6	13.0	13.8	
	14.6	14.2	13.4	11.4	13.2	14.0	
	14.6	14.4	12.0	11.4	13.0	13.6	
	14.2	14.4	12.2	11.6	13.6	13.6	
	14.6	13.6	13.0	11.8	13.6	14.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.11 ELECTROPHORESIS OF COLLIERY WASTE-WATER AS pH = 6.0

CONDUCTIVITY (λ) = 1.50 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	19.11	19.08	19.12	19.14	19.11	19.16	
I(amp)	3.33	3.33	3.33	3.34	3.33	3.34	x10^{-3}
R(ohm)	5.74	5.73	5.73	5.73	5.74	5.73	x10^{3}
l(m)	8.61	8.59	8.61	8.60	8.61	8.60	x10^{-2}
E(volt m-1)	2.22	2.22	2.22	2.23	2.22	2.23	x10^{2}

14.6	13.8	12.0	11.8	12.6	13.8
14.4	13.6	12.6	11.6	13.2	14.2
15.4	14.0	13.2	11.0	13.0	14.0
15.0	14.2	13.0	12.0	12.8	14.6
15.4	13.4	12.8	11.2	13.6	14.2
14.8	13.0	12.2	11.8	13.8	14.8
15.2	13.2	12.4	11.4	13.0	14.6
14.2	14.2	13.0	12.2	12.8	14.4
14.8	13.4	12.4	12.2	13.2	14.0
14.2	13.2	12.8	11.4	13.4	14.6
14.6	14.0	12.8	11.2	13.0	14.8
15.2	13.6	12.2	11.8	13.6	14.4
15.4	14.2	12.6	11.6	13.8	14.2
14.2	13.8	12.4	11.4	13.4	13.8
15.0	13.0	12.4	12.0	12.6	14.4
14.4	13.8	12.2	11.2	13.2	14.2

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN.

TABLE D.12 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 6.0

CONDUCTIVITY (λ) = 1.50 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	19.16	19.17	19.08	19.15	19.08	19.10	
I(amp)	3.34	3.34	3.33	3.34	3.33	3.33	x10^{-3}
R(ohm)	5.74	5.74	5.73	5.73	5.73	5.74	x10^{3}
l(m)	8.60	8.61	8.59	8.60	8.59	8.60	x10^{-2}
E(volt m^{-1})	2.23	2.23	2.22	2.23	2.22	2.22	x10^{2}
	13.6	14.2	12.8	11.2	12.8	14.6	
	14.0	13.8	13.2	11.6	13.2	13.8	
	14.2	13.6	12.6	11.6	13.4	14.8	
	13.8	13.2	12.4	12.2	12.8	15.2	
	13.8	13.0	13.6	12.0	14.4	15.2	
	14.4	12.8	13.4	11.0	14.8	15.0	
	14.0	13.0	13.0	11.8	14.6	14.8	
	13.6	13.4	12.6	11.4	13.0	13.8	
	14.4	14.0	12.4	11.8	13.8	14.8	
	14.6	13.6	12.2	11.0	14.4	15.4	
	14.0	13.4	12.2	11.2	14.6	14.6	
	14.6	13.2	12.8	11.4	13.8	14.6	
	14.2	13.6	13.4	11.4	13.6	14.4	
	14.2	13.8	13.2	12.0	14.8	15.2	
	14.8	14.2	13.0	11.6	14.4	14.6	
	14.8	13.6	13.0	12.0	13.2	15.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.13 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.3

CONDUCTIVITY (λ) = 1.55 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(Volt)	18.49	18.51	18.50	18.49	18.52	18.55	
I(amp)	3.34	3.34	3.34	3.34	3.34	3.35	x10^{-3}
R(ohm)	5.54	5.54	5.54	5.54	5.54	5.54	x10^{3}
l(m)	8.59	8.59	8.59	8.59	8.59	8.58	x10^{-2}
E(volt m^{-1})	2.15	2.15	2.15	2.15	2.15	2.16	x10^{2}
	14.8	13.2	12.8	11.8	12.4	13.2	
	15.0	13.4	13.0	12.0	12.6	14.0	
	14.2	13.8	12.6	11.6	12.0	14.2	
	14.4	13.6	13.4	11.4	13.0	14.0	
	15.0	14.0	13.2	11.0	13.0	13.6	
	14.6	13.0	12.4	12.0	12.2	13.4	
	14.4	13.2	12.2	11.8	12.6	13.8	
	14.2	14.2	12.0	11.2	12.8	13.0	
	14.6	13.6	12.6	11.4	12.8	13.8	
	14.6	13.4	12.2	11.2	12.4	13.6	
	14.0	13.0	12.8	11.0	12.0	14.2	
	14.0	14.0	13.2	12.0	12.6	13.0	
	14.2	13.2	12.0	11.6	13.0	13.4	
	14.4	13.8	13.0	11.4	12.4	13.2	
	14.8	13.4	13.4	11.0	12.2	13.6	
	14.4	13.2	12.4	11.2	12.2	13.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.14 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.3

CONDUCTIVITY (λ) = $1.55\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	18.51	18.50	18.44	18.45	18.48	18.49	
I(amp)	3.34	3.34	3.33	3.33	3.33	3.34	$\times 10^{-3}$
R(ohm)	5.54	5.54	5.54	5.54	5.55	5.54	$\times 10^{3}$
l(m)	8.59	8.59	8.58	8.59	8.60	8.59	$\times 10^{-2}$
E(volt m^{-1})	2.15	2.15	2.15	2.15	2.15	2.15	$\times 10^{2}$
	14.6	13.4	12.6	11.2	12.4	13.4	
	15.2	13.8	12.4	11.6	12.6	13.6	
	14.8	13.6	12.8	11.8	12.4	13.8	
	14.4	14.2	13.0	11.6	13.2	14.4	
	13.6	14.0	12.4	11.4	13.0	14.6	
	13.8	13.4	12.2	11.2	12.8	14.0	
	14.2	13.8	12.6	11.0	13.4	14.2	
	14.0	13.2	13.2	11.4	12.8	14.4	
	14.0	13.2	13.0	11.6	12.8	13.8	
	14.6	13.6	12.6	11.2	12.6	13.4	
	14.2	14.0	12.8	11.0	12.2	14.0	
	14.2	13.8	12.8	11.8	13.0	14.4	
	15.0	14.2	13.2	11.4	12.4	14.2	
	14.8	13.2	12.4	11.4	13.2	14.6	
	14.4	13.4	12.2	11.2	12.4	14.4	
	14.6	13.6	12.2	11.2	12.6	13.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.15 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.3

CONDUCTIVITY (λ)	= 1.55 10^{-1} ohm^{-1} m^{-1}
CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A)	= 1.0 10^{-4} m^2
DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X)	= 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$x10^{-2}$
V(volt)	18.46	18.51	18.54	18.5	18.53	18.55	
I(amp)	3.33	3.34	3.34	3.35	3.34	3.35	$x10^{-3}$
R(ohm)	5.54	5.54	5.55	5.54	5.54	5.54	$x10^{3}$
l(m)	8.59	8.59	8.60	8.58	8.61	8.58	$x10^{-2}$
E(volt m^{-1})	2.15	2.15	2.15	2.16	2.15	2.16	$x10^{2}$
	14.4	13.6	12.8	12.0	12.0	13.2	
	15.2	13.8	13.2	11.8	12.4	13.4	
	15.4	14.2	13.4	11.2	13.0	14.2	
	15.6	13.4	13.6	11.0	12.6	13.6	
	14.6	14.0	13.0	11.4	12.8	13.8	
	14.2	14.4	12.4	11.8	12.2	14.2	
	14.4	13.4	12.6	11.2	12.6	14.0	
	14.8	13.6	13.2	11.6	12.4	13.6	
	14.2	13.8	13.4	11.0	13.0	13.8	
	15.4	14.0	13.6	11.0	12.6	13.2	
	14.6	14.4	12.8	11.6	12.8	13.6	
	15.2	13.6	13.0	11.8	12.4	13.6	
	15.6	14.2	12.6	11.6	12.2	13.4	
	14.8	14.4	12.4	11.2	12.6	14.0	
	14.6	13.4	12.8	11.4	12.4	13.6	
	14.4	13.8	12.6	12.0	12.6	13.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.16 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.3

CONDUCTIVITY (λ) = $1.55\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	18.52	18.54	18.49	18.52	18.51	18.54	
I(amp)	3.34	3.34	3.34	3.34	3.34	3.34	x10^{-3}
R(ohm)	5.54	5.55	5.54	5.54	5.54	5.55	x10^{3}
l(m)	8.59	8.60	8.59	8.59	8.59	8.60	x10^{-2}
E(volt m-1)	2.15	2.15	2.15	2.15	2.15	2.15	x10^{2}
	14.2	13.4	12.8	12.0	12.4	13.6	
	14.8	13.6	12.6	11.2	12.8	13.8	
	15.4	13.8	12.0	11.2	13.2	13.2	
	15.2	14.2	12.2	11.4	13.0	14.2	
	15.4	13.4	13.0	11.8	12.6	14.0	
	14.6	14.0	13.0	12.0	12.4	13.4	
	15.0	13.6	12.4	11.6	13.4	14.4	
	15.0	14.4	12.8	11.8	12.8	14.6	
	14.6	13.8	12.4	11.2	12.6	14.4	
	15.2	14.0	12.2	11.8	13.2	13.6	
	14.8	13.4	12.6	11.4	12.8	13.4	
	14.4	14,2	12.8	12.0	12.4	13.2	
	14.2	13.6	12.2	12.0	12.8	14.6	
	14.4	13.4	12.6	11.0	13.4	14.2	
	14.0	14.0	12.0	11.0	13.0	13.8	
	14.0	14.2	12.4	11.2	12.6	14.0	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.17 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.0

CONDUCTIVITY (λ) = 1.56 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	18.10	18.08	18.09	18.12	18.06	18.07	
I(amp)	3.29	3.28	3.28	3.29	3.28	3.28	x10^{-3}
R(ohm)	5.50	5.51	5.52	5.51	5.51	5.51	x10^{3}
l(m)	8.58	8.60	8.60	8.59	8.59	8.59	x10^{-2}
E(volt m^{-1})	2.11	2.10	2.10	2.11	2.10	2.10	x10^{2}
	14.6	13.4	12.2	11.2	12.4	14.2	
	15.0	13.2	12.4	11.0	12.6	13.6	
	14.8	12.8	12.6	11.6	13.4	13.8	
	13.8	12.6	12.2	11.2	13.0	13.4	
	14.0	13.0	12.0	11.8	13.2	14.0	
	13.6	13.0	13.0	11.4	13.0	13.6	
	13.8	12.6	13.2	12.0	12.8	14.4	
	13.8	13.6	12.8	11.8	13.6	14.6	
	13.6	12.8	12.0	11.4	12.8	14.4	
	14.0	12.8	12.6	11.2	12.4	13.8	
	14.4	13.4	12.8	11.0	13.2	14.0	
	15.0	13.0	13.0	11.8	13.4	13.6	
	14.6	12.6	12.2	11.6	13.6	13.4	
	14.4	13.2	12.4	12.0	12.6	13.8	
	14.2	13.2	12.0	11.2	13.6	14.6	
	14.0	12.8	13.2	11.4	12.8	14.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.18 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.0

CONDUCTIVITY (λ) = $1.56\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	18.11	18.13	18.14	18.12	18.11	18.15	
I(amp)	3.29	3.29	3.29	3.29	3.29	3.29	x10^{-3}
R(ohm)	5.50	5.51	5.51	5.51	5.50	5.52	x10^{3}
l(m)	8.59	8.60	8.60	8.59	8.59	8.61	x10^{-2}
E(volt m-1)	2.11	2.11	2.11	2.11	2.11	2.11	x10^{2}
	14.0	13.8	12.2	11.4	12.4	14.0	
	13.8	13.6	12.0	11.6	13.0	14.2	
	14.6	13.4	12.4	11.2	12.6	13.6	
	15.0	13.0	12.6	12.0	12.8	13.8	
	14.8	13.8	13.2	11.6	13.2	14.2	
	14.4	13.6	13.0	11.8	13.4	14.2	
	14.2	13.2	12.8	11.0	12.8	14.0	
	14.6	13.4	12.6	11.2	13.4	14.4	
	14.4	13.4	12.6	11.0	13.4	14.6	
	15.0	13.2	13.0	11.2	12.6	14.4	
	14.8	13.0	12.2	11.8	12.4	14.6	
	14.2	13.8	12.2	11.4	13.2	13.8	
	14.6	13.6	12.8	11.4	12.6	14.8	
	14.6	13.4	13.2	12.0	12.4	13.6	
	13.8	13.8	12.0	11.6	12.8	13.8	
	14.4	13.2	12.4	11.2	12.8	14.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.19 ELECTROPHORESIS OF THE COLLIERY WASTE-WATER AT pH = 5.0

CONDUCTIVITY (λ) = $1.56\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	18.13	18.14	18.12	18.15	18.08	18.12	
I(amp)	3.29	3.29	3.29	3.29	3.28	3.29	x10^{-3}
R(ohm)	5.51	5.51	5.51	5.52	5.51	5.51	x10^{3}
l(m)	8.60	8.60	8.59	8.61	8.60	8.59	x10^{-2}
E(volt m-1)	2.11	2.11	2.11	2.11	2.10	2.11	x10^{2}
	13.8	13.6	12.8	11.8	12.6	13.4	
	14.2	13.2	12.4	11.6	12.4	13.0	
	14.4	13.0	13.0	12.0	12.2	14.2	
	14.6	13.0	12.2	11.4	13.4	13.8	
	14.0	13.4	12.4	11.6	13.6	13.6	
	14.8	13.8	12.6	11.4	12.8	13.6	
	14.6	14.0	13.2	11.2	13.0	14.0	
	14.2	13.8	13.2	11.4	13.2	14.4	
	14.4	13.4	12.4	11.2	13.4	13.8	
	13.8	13.6	12.2	11.8	12.8	13.4	
	13.8	13.2	12.2	11.4	13.0	14.0	
	14.2	13.0	12.6	12.0	12.6	14.4	
	14.8	13.2	12.8	12.0	13.2	14.2	
	14.4	14.0	12.8	11.2	12.4	13.0	
	14.0	14.0	13.0	11.8	13.6	14.4	
	14.4	13.4	12.4	11.2	12.2	13.8	
	TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN.						

TABLE D.20 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 5.0

CONDUCTIVITY (λ) = $1.56\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE POSITIVE ELECTRODE							
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	18.16	18.20	18.22	18.25	18.21	18.23	
I(amp)	3.30	3.30	3.30	3.30	3.30	3.30	$\times 10^{-3}$
R(ohm)	5.50	5.52	5.52	5.53	5.52	5.52	$\times 10^{3}$
l(m)	8.58	8.60	8.61	8.63	8.61	8.62	$\times 10^{-2}$
E(volt m^{-1})	2.12	2.12	2.12	2.12	2.12	2.12	$\times 10^{2}$
	14.4	13.2	12.4	12.2	12.6	13.6	
	14.8	14.0	12.6	12.4	13.0	14.2	
	14.2	13.8	12.8	12.0	12.0	14.0	
	14.4	14.2	13.2	11.8	12.8	14.4	
	14.6	13.6	13.0	11.6	12.2	13.8	
	15.0	13.4	12.0	12.4	12.6	13.4	
	15.2	13.8	12.2	11.4	13.0	13.6	
	14.8	13.2	12.6	11.2	12.4	14.0	
	15.0	13.8	12.2	12.4	12.2	13.8	
	14.6	14.2	12.8	11.8	12.0	14.4	
	14.2	13.4	12.0	12.2	12.6	13.4	
	14.6	13.6	13.0	12.4	12.4	14.0	
	14.4	14.2	12.4	11.6	12.8	13.6	
	15.2	13.2	13.2	11.2	12.0	14.2	
	14.6	14.0	12.6	11.8	12.6	13.8	
	14.2	13.6	12.4	11.4	12.4	14.4	

TIME (SEC) TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.21 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = $1.62\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	$\times 10^{-2}$
V(volt)	17.72	17.74	17.73	17.76	17.75	17.71	
I(amp)	3.33	3.33	3.33	3.34	3.33	3.33	$\times 10^{-3}$
R(ohm)	5.32	5.33	5.32	5.32	5.33	5.32	$\times 10^{3}$
l(m)	8.62	8.63	8.63	8.61	8.64	8.62	$\times 10^{-2}$
E(volt m^{-1})	2.06	2.06	2.06	2.06	2.06	2.06	$\times 10^{2}$
	14.4	13.2	12.8	12.0	12.4	13.4	
	14.2	13.4	12.6	11.8	13.0	13.8	
	13.8	13.6	12.6	11.2	12.8	14.0	
	13.6	13.0	12.0	11.6	12.6	14.2	
	13.6	13.0	12.4	11.8	13.0	14.6	
	14.0	13.8	12.2	11.2	13.6	14.2	
	14.6	13.2	13.0	11.0	13.4	13.8	
	14.8	13.8	13.2	11.4	12.4	14.4	
	14.0	13.4	12.4	11.6	12.6	14.0	
	14.4	13.0	12.8	11.0	13.6	13.6	
	14.6	13.2	13.2	11.0	13.2	14.2	
	14.2	13.6	12.4	12.0	13.4	14.4	
	14.8	13.4	12.0	11.6	13.2	14.6	
	13.6	13.4	13.0	11.8	12.8	14.0	
	14.2	13.6	12.2	11.4	12.4	13.6	
	14.0	13.8	12.6	11.2	13.0	13.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.22 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = $1.62\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$\times 10^{-2}$
V(volt)	17.71	17.74	17.69	17.70	17.68	17.71	
I(amp)	3.33	3.33	3.33	3.33	3.32	3.33	$\times 10^{-3}$
R(ohm)	5.32	5.33	5.31	5.32	5.33	5.32	$\times 10^{3}$
l(m)	8.62	8.63	8.61	8.61	8.63	8.62	$\times 10^{-2}$
E(volt m^{-1})	2.06	2.06	2.06	2.06	2.05	2.06	$\times 10^{2}$
	13.8	13.8	13.2	11.8	12.2	13.4	
	14.2	14.0	12.6	11.6	12.6	13.8	
	14.6	13.4	12.8	11.4	12.8	12.8	
	13.8	13.6	12.4	11.2	12.2	13.0	
	14.8	13.2	12.2	11.0	13.0	12.8	
	15.0	12.8	13.0	12.2	12.8	13.6	
	15.2	14.2	12.4	12.0	12.4	13.8	
	15.0	14.4	12.6	11.8	13.2	14.2	
	14.4	14.6	13.0	11.6	12.0	14.4	
	14.8	14.2	12.4	11.0	12.4	14.2	
	14.2	14.0	12.6	11.2	12.6	14.0	
	14.4	13.6	12.8	11.8	13.2	13.6	
	14.6	13.8	13.2	12.0	12.0	14.4	
	13.8	13.4	12.2	11.4	13.0	14.6	
	14.0	13.0	12.4	11.0	12.6	14.0	
	14.0	13.0	12.2	11.2	12.2	14.6	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.23 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = 1.62 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE							
d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	17.66	17.67	17.74	17.76	17.71	17.69	
I(amp)	3.32	3.32	3.33	3.34	3.33	3.33	x10^{-3}
R(ohm)	5.32	5.32	5.33	5.32	5.32	5.31	x10^{3}
l(m)	8.62	8.62	8.63	8.61	8.62	8.61	x10^{-2}
E(volt m^{-1})	2.05	2.05	2.06	2.06	2.06	2.06	x10^{2}
	15.0	13.8	12.6	11.4	12.8	13.4	
	14.8	14.0	12.8	11.0	13.4	14.0	
	13.6	13.2	12.4	11.0	13.2	14.2	
	13.8	13.0	13.0	11.4	12.6	13.8	
	14.0	13.6	13.2	11.2	13.6	13.6	
	14.4	13.8	12.0	11.8	13.0	14.4	
	14.6	13.4	12.2	11.6	13.8	14.6	
	14.2	14.0	12.6	12.0	12.6	14.4	
	13.8	13.6	13.0	11.6	13.0	14.8	
	14.4	13.2	12.6	11.4	13.2	13.8	
	14.2	13.4	12.2	11.2	12.8	13.4	
	14.8	14.0	13.2	11.2	12.8	14.0	
	14.2	13.8	12.4	11.8	12.6	14.6	
	15.0	13.4	12.0	12.0	13.4	13.6	
	13.6	13.0	12.8	11.8	13.4	14.2	
	14.6	13.2	12.4	11.2	13.0	14.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.24 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 4.0

CONDUCTIVITY (λ) = 1.62 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	17.74	17.73	17.67	17.68	17.69	17.74	
I(amp)	3.33	3.33	3.32	3.32	3.33	3.33	$x10^{-3}$
R(ohm)	5.33	5.32	5.32	5.33	5.31	5.33	$x10^{3}$
l(m)	8.63	8.63	8.62	8.63	8.61	8.63	$x10^{-2}$
E(volt m^{-1})	2.06	2.06	2.05	2.05	2.06	2.06	$x10^{2}$
	14.6	13.2	12.8	11.6	12.6	14.2	
	13.8	13.0	12.6	11.2	12.4	13.8	
	14.2	13.4	12.0	11.4	13.2	13.6	
	14.0	13.0	12.2	11.8	13.0	14.0	
	14.4	13.6	12.6	11.8	12.8	14.4	
	14.8	13.8	12.4	11.0	13.0	14.4	
	14.8	14.0	12.8	11.0	13.2	14.8	
	14.6	13.8	12.0	11.4	13.4	14.6	
	13.8	13.0	13.0	12.0	12.8	14.0	
	14.0	13.8	13.0	11.6	12.4	13.6	
	13.8	13.6	12.8	11.2	12.6	13.4	
	14.4	13.2	12.4	11.4	13.4	13.4	
	14.2	13.4	12.2	11.0	13.0	13.8	
	14.0	13.4	12.2	11.4	12.6	14.2	
	14.2	13.0	12.0	11.6	12.6	14.6	
	14.4	13.2	12.4	12.0	12.4	14.8	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.25 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 3.0

CONDUCTIVITY (λ) = 2.00 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	17.30	17.32	17.29	17.30	17.31	17.35	
I(amp)	4.02	4.03	4.02	4.02	4.02	4.03	x10^{-3}
R(ohm)	4.30	4.30	4.30	4.30	4.31	4.31	x10^{3}
l(m)	8.61	8.60	8.60	8.61	8.61	8.61	x10^{-2}
E(volt m^{-1})	2.01	2.02	2.01	2.01	2.01	2.02	x10^{2}

13.6	12.8	12.8	12.2	12.4	12.8
13.8	12.6	12.2	11.8	12.8	12.4
14.0	13.4	12.4	11.6	13.2	13.0
14.2	13.0	12.2	11.2	13.6	13.4
13.4	13.2	12.0	12.0	12.0	12.6
14.0	13.0	12.6	11.8	12.6	12.8
13.2	12.6	13.0	11.0	12.8	13.2
14.2	12.8	12.6	11.4	12.0	13.0
13.4	13.6	12.2	11.0	12.2	13.4
13.0	13.4	12.0	11.2	12.6	12.6
13.0	13.0	12.4	11.8	12.8	12.8
13.2	12.6	12.4	12.2	12.0	13.2
13.8	13.0	12.2	12.0	12.4	13.0
13.6	12.8	13.0	11.6	12.2	13.0
13.4	13.2	12.8	11.2	12.2	12.4
13.6	13.2	12.4	11.4	12.8	12.6

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.26 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 3.0

CONDUCTIVITY (λ) = 2.0 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

MIGRATION TOWARDS THE POSITIVE ELECTRODE

d(m)	4.05	4.10	4.15	4.20	4.25	4.30	$x10^{-2}$
V(volt)	17.36	17.33	17.32	17.35	17.34	17.37	
I(amp)	4.03	4.03	4.03	4.03	4.03	4.03	$x10^{-3}$
R(ohm)	4.31	4.30	4.30	4.31	4.30	4.31	$x10^{3}$
l(m)	8.62	8.60	8.60	8.61	8.61	8.62	$x10^{-2}$
E(volt m^{-1})	2.02	2.02	2.02	2.02	2.02	2.02	$x10^{2}$
	14.4	12.8	12.6	11.4	12.8	13.4	
	14.0	13.0	12.8	11.2	13.0	13.6	
	13.8	12.6	12.2	11.0	13.4	14.0	
	13.6	12.4	12.8	12.0	12.6	14.4	
	13.0	12.8	12.2	11.8	12.4	14.6	
	14.2	13.2	12.4	11.4	12.8	14.2	
	14.0	13.4	12.6	11.2	13.2	13.8	
	13.4	12.6	13.0	11.6	13.0	14.0	
	13.6	13.4	12.4	11.6	12.6	14.2	
	14.2	13.6	13.0	11.8	13.0	13.6	
	14.0	13.8	12.2	11.2	13.2	14.4	
	13.8	13.0	12.4	11.2	12.4	13.4	
	13.4	12.4	12.8	12.0	12.8	13.8	
	13.2	13.4	12.6	11.0	13.4	14.6	
	14.4	13.0	12.4	11.4	12.8	13.6	
	14.2	13.6	13.0	11.4	12.4	13.4	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.27 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 3.0

CONDUCTIVITY (λ) = $2.0\ 10^{-1}$ ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = $1.0\ 10^{-4}$ m^{2}

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = $28.0\ 10^{-2}$ m

CIRCUIT REVERSED

MIGRATION TOWARDS THE NEGATIVE ELECTRODE

d(m)	3.70	3.75	3.80	3.85	3.90	3.95	x10^{-2}
V(volt)	17.34	17.36	17.33	17.31	17.32	17.36	
I(amp)	4.03	4.03	4.03	4.02	4.03	4.03	x10^{-3}
R(ohm)	4.30	4.31	4.30	4.31	4.30	4.31	x10^{3}
l(m)	8.61	8.62	8.60	8.61	8.60	8.62	x10^{-2}
E(volt m^{-1})	2.02	2.02	2.02	2.01	2.02	2.02	x10^{2}
	14.0	12.6	12.4	11.2	12.4	13.0	
	13.8	13.4	12.8	11.8	12.2	13.4	
	14.4	13.2	12.2	11.4	12.8	13.8	
	14.0	13.0	13.0	11.6	13.0	13.6	
	14.2	13.4	13.2	11.0	12.6	14.2	
	13.6	12.8	12.0	12.0	12.4	14.0	
	13.4	12.4	12.4	11.6	12.0	13.2	
	14.2	13.6	12.6	12.0	12.8	13.4	
	14.4	13.6	12.2	11.4	13.0	13.8	
	13.6	12.8	12.6	11.2	12.6	14.2	
	13.8	12.6	13.0	11.0	12.0	13.6	
	14.2	13.0	12.8	11.0	12.0	14.0	
	13.6	13.0	12.2	11.8	12.4	13.4	
	13.4	13.6	12.4	11.6	12.2	13.2	
	13.8	13.2	12.0	12.0	13.0	13.0	
	14.0	13.2	12.4	11.0	12.6	13.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

TABLE D.28 ELECTROPHORESIS OF COLLIERY WASTE-WATER AT pH = 3.0

CONDUCTIVITY (λ) = 2.0 10^{-1} ohm^{-1} m^{-1}

CROSS-SECTIONAL AREA OF THE ELECTROPHORETIC CELL (A) = 1.0 10^{-4} m^2

DISTANCE TRAVELLED BY THE PARTICLES ON THE TELEVISION SCREEN (X) = 28.0 10^{-2} m

CIRCUIT REVERSED

	MIGRATION TOWARDS THE POSITIVE ELECTRODE						
d(m)	4.05	4.10	4.15	4.20	4.25	4.30	x10^{-2}
V(volt)	17.32	17.35	17.30	17.28	17.34	17.35	
I(amp)	4.03	4.02	4.02	4.02	4.03	4.03	x10^{-3}
R(ohm)	4.30	4.31	4.30	4.30	4.30	4.31	x10^{3}
l(m)	8.60	8.61	8.61	8.60	8.61	8.61	x10^{-2}
E(volt m^{-1})	2.02	2.02	2.01	2.01	2.02	2.02	x10^{2}
	14.2	13.2	12.8	11.4	12.4	13.4	
	14.0	13.0	12.6	11.2	12.8	13.2	
	13.8	13.8	12.4	11.8	13.0	13.8	
	13.8	13.8	12.0	11.0	12.6	14.2	
	14.4	13.0	13.0	11.6	12.4	14.0	
	13.6	12.8	13.2	12.0	13.2	14.4	
	14.0	13.4	12.8	12.2	13.4	13.6	
	14.6	13.6	12.2	11.4	13.0	14.0	
	14.2	13.0	13.0	12.2	12.6	13.8	
	13.6	13.6	12.4	11.6	12.4	13.4	
	13.8	13.2	12.2	11.8	12.8	14.0	
	13.6	13.4	12.0	11.2	13.4	13.6	
	14.0	13.4	13.2	11.0	12.6	14.4	
	14.2	13.0	12.8	11.0	13.0	14.2	
	14.6	13.6	12.6	11.2	13.2	13.8	
	14.4	13.2	12.4	11.4	12.6	13.2	

TIME (SEC) TAKEN TO TRAVEL THE DISTANCE ON THE TELEVISION SCREEN

DEFINITIONS

Electrophoresis is the movement of a charged surface material relative to stationary liquid by an applied electric field.

Electro-osmosis is the movement of liquid relative to a stationary charged surface by an applied electric field.

Streaming potential is the electric field which is created when liquid is made to flow along a stationary charged surface.

Sedimentation potential is the electric field which is created when charged particles move relative to the stationary liquid.

VARIATION OF pH WITH CONDUCTIVITY - 2000cc OF COLLIERY WASTEWATER IN 0.4MHCℓ

HCℓ	pH	Conductivity (ohm^{-1} m^{-1})	HCℓ	pH	Conductivity (ohm^{-1} m^{-1})	HCℓ	pH	Conductivity (ohm^{-1} m^{-1})
0.0	8.60	$1.360\ 10^{-1}$	50.0	6.33	$1.50\ 10^{-1}$	88.0	3.65	$1.75\ 10^{-1}$
1.0	8.45	$1.365\ 10^{-1}$	60.0	6.10	$1.55\ 10^{-1}$	90.0	3.40	$1.81\ 10^{-1}$
2.0	8.30	$1.370\ 10^{-1}$	65.0	6.00	$1.58\ 10^{-1}$	95.0	3.10	$2.00\ 10^{-1}$
3.0	8.15	$1.375\ 10^{-1}$	70.0	5.85	$1.59\ 10^{-1}$	100.0	2.90	$2.20\ 10^{-1}$
5.0	7.80	$1.380\ 10^{-1}$	75.0	5.65	$1.60\ 10^{-1}$	110.0	2.70	$2.58\ 10^{-1}$
6.0	7.60	$1.390\ 10^{-1}$	80.0	5.30	$1.61\ 10^{-1}$	130.0	2.50	$3.20\ 10^{-1}$
7.0	7.60	$1.390\ 10^{-1}$	82.0	5.10	$1.61\ 10^{-1}$	150.0	2.35	$4.08\ 10^{-1}$
8.0	7.55	$1.40\ 10^{-1}$	83.0	4.98	$1.61\ 10^{-1}$	175.0	2.20	$4.96\ 10^{-1}$
10.0	7.42	$1.41\ 10^{-1}$	83.5	4.85	$1.61\ 10^{-1}$	200.0	2.10	$5.80\ 10^{-1}$
15.0	7.15	$1.43\ 10^{-1}$	84.0	4.80	$1.62\ 10^{-1}$	250.0	1.95	$7.40\ 10^{-1}$
20.0	7.00	$1.44\ 10^{-1}$	85.0	4.45	$1.64\ 10^{-1}$	300.0	1.85	$8.00\ 10^{-1}$
30.0	6.75	$1.46\ 10^{-1}$	86.0	4.05	$1.68\ 10^{-1}$	350.0	1.80	$10.80\ 10^{-1}$
41.0	6.50	$1.48\ 10^{-1}$	87.0	3.80	$1.70\ 10^{-1}$	400.0	1.70	$11.80\ 10^{-1}$

VARIATION OF pH WITH CONDUCTIVITY - 1000cc.OF COLLIERY WASTEWATER 0.4M.H_2SO_4

H_2SO_4	pH	Conductivity (ohm^{-1}m^{-1})	H_2SO_4 (cc)	pH	Conductivity (ohm^{-1} m^{-1})	H_2SO_4	pH	Conductivity
0.00	8.80	$1.34\ 10^{-1}$	11.0	5.70	$1.52\ 10^{-1}$	16.00	2.85	$2.22\ 10^{-1}$
0.50	8.35	$1.35\ 10^{-1}$	11.50	5.60	$1.54\ 10^{-1}$	18.00	2.70	$2.62\ 10^{-1}$
1.00	7.70	$1.36\ 10^{-1}$	12.00	5.30	$1.55\ 10^{-1}$	20.10	2.55	$3.02\ 10^{-1}$
1.50	7.50	$1.37\ 10^{-1}$	12.20	5.25	$1.55\ 10^{-1}$	25.00	2.35	$3.90\ 10^{-1}$
2.00	7.30	$1.38\ 10^{-1}$	12.50	5.00	$1.56\ 10^{-1}$	30.00	2.20	$4.90\ 10^{-1}$
3.00	7.05	$1.39\ 10^{-1}$	12.60	4.80	$1.56\ 10^{-1}$	40.00	2.00	$6.60\ 10^{-1}$
4.00	6.80	$1.41\ 10^{-1}$	12.70	4.70	$1.58\ 10^{-1}$	50.00	1.90	$8.40\ 10^{-1}$
5.00	6.65	$1.42\ 10^{-1}$	12.80	4.45	$1.59\ 10^{-1}$	60.10	1.80	$10.00\ 10^{-1}$
6.00	6.50	$1.44\ 10^{-1}$	13.00	4.00	$1.62\ 10^{-1}$	80.00	1.70	$13.00\ 10^{-1}$
7.00	6.40	$1.45\ 10^{-1}$	13.20	3.75	$1.65\ 10^{-1}$	100.00	1.60	$16.20\ 10^{-1}$
8.00	6.25	$1.47\ 10^{-1}$	13.50	3.50	$1.72\ 10^{-1}$			
9.00	6.10	$1.49\ 10^{-1}$	14.00	3.30	$1.80\ 10^{-1}$			
10.00	5.95	$1.50\ 10^{-1}$	15.00	3.00	$2.00\ 10^{-1}$			

VARIATION OF pH WITH CONDUCTIVITY- 1000cc OF 100p.p.m IN QUARTZ IN 0.4M.HCℓ

HCℓ (cc)	pH	Conductivity (ohm^{-1} m^{-1}	HCℓ (cc)	pH	Conductivity (ohm^{-1} m^{-1}
0.00	5.18	$3.92\ 10^{-4}$	7.00	3.30	$338.\ 10^{-4}$
0.10	4.90	$6.60\ 10^{-4}$	10.00	3.16	$488.\ 10^{-4}$
0.20	4.74	$9.00\ 10^{-4}$	15.00	3.00	$730.\ 10^{-4}$
0.30	4.55	$14.10\ 10^{-4}$	25.00	2.85	$1.21\ 10^{-1}$
0.40	4.40	$19.80\ 10^{-4}$	35.00	2.75	$1.72\ 10^{-1}$
0.50	4.30	$25.20\ 10^{-4}$	50.00	2.60	$2.40\ 10^{-1}$
0.70	4.20	$34.0\ 10^{-4}$	70.00	2.40	$3.30\ 10^{-1}$
1.00	4.05	$48.0\ 10^{-4}$	100.00	2.30	$4.70\ 10^{-1}$
1.20	3.95	$60.00\ 10^{-4}$	150.00	2.10	$6.70\ 10^{-1}$
1.50	3.85	$75.00\ 10^{-4}$	200.00	2.05	$8.50\ 10^{-1}$
2.00	3.80	$94.0\ 10^{-4}$	250.00	1.95	$10.40\ 10^{-1}$
3.00	3.65	$145.0\ 10^{-4}$			
5.00	3.50	$240.0\ 10^{-4}$			

VARIATION OF pH WITH CONDUCTIVITY- 1000cc OF 100p.p.m. IN QUARTZ in 0.4M H_2SO_4

H_2SO_4 (cc)	pH	Conductivity (ohm^{-1}m^{-1})	H_2SO_4 (cc)	pH	Conductivity (ohm^{-1}m^{-1})
0.00	5.18	$3.70\ 10^{-4}$	30.00	2.15	$6.0\ 10^{-1}$
0.10	4.30	$27.80\ 10^{-4}$	50.00	2.00	$9.25\ 10^{-1}$
0.25	3.95	$62.00\ 10^{-4}$	75.00	1.85	$12.90\ 10^{-1}$
0.40	3.75	$110.0\ 10^{-4}$	100.00	1.80	$16.50\ 10^{-1}$
0.50	3.65	$145.0\ 10^{-4}$	150.00	1.70	$22.80\ 10^{-1}$
1.00	3.40	$265.0\ 10^{-4}$	200.00	1.60	$28.0\ 10^{-1}$
2.00	3.10	$520.\ 10^{-4}$	250.00	1.50	$32.80\ 10^{-1}$
3.00	3.00	$770.\ 10^{-4}$			
5.00	2.80	$1.22\ 10^{-1}$			
7.00	2.65	$1.70\ 10^{-1}$			
10.00	2.55	$2.30\ 10^{-1}$			
15.00	2.40	$3.28\ 10^{-1}$			
20.00	2.30	$4.18\ 10^{-1}$			