THE USE OF PHOTOGRAPHIC PLATES AS AN AID TO COSMIC RAY INVESTIGATIONS *

BY D. M. BOSE

This is the second occasion on which I have the opportunity of addressing an annual meeting of the Indian Physical Society. The past year has been marked by an intensification of the war in Europe, by an increased effort made in this country to produce in larger measure the materials required for a successful prosecution of the war in the near East, and also to manufacture articles whose supply from Europe and America have been cut off as a result of the war. A Board of Scientific and Industrial Research has been created under the able and energetic directorship of Professor S. S. Bhatnagar. Sub-committees have been appointed to investigate and work out schemes of research for the production of technologically important articles. Researches in technical physics have been directed towards the production of optical glasses, scientific instruments, wireless goods and allied articles. This recent development of research in technical physics has again brought up to my mind the question once put to me by a friend of mine in Bombay in 1928, at the time when Sir C. V. Raman had made his epoch-making discovery of the effect associated with his name. The question put to me was that why Indians, who have made such fundamental discoveries in pure physics, were so tardy in working out technological inventions. It appears to me that the present time is suitable for a review of the development of the various sciences, pure and applied, in this country since the advent of the British, and of their applications to the welfare of this country. The whole problem could be reviewed from the standpoint which is so widespread at present in some of the western countries, that scientific development at any epoch takes place in response to the social requirements of the period. I had at first intended to take up this theme as the subject of my address before you to-day. Subsequently I discovered that the time at my disposal was not sufficient for a satisfactory investigation and an adequate presentation of the subject. I have therefore decided to present before you a short review of a subject which has been engaging my attention during the last two years, *viz.*, the use of photographic plates as a means of investigation of problems of nuclear physics and of cosmic rays, the stress being laid on investigations in the last-named subject.

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* Presidential address of Dr. D. M. Bose before the annual meeting of the Indian Physical Society held at Benares.

As you are aware that the effects produced accidentally on photographic plates led to the discovery of X-rays by Röntgen and of radiations from uranium compounds by Becquerel. In those days photographic plates formed an indispensable adjunct in such investigations, but subsequent development of sensitive methods of measuring ionisation currents, the development of Wilson's cloud chamber and of the counter-tube arrangements by Geiger placed the photographic plate in the background. Recently the photagraphic plate has been found of great help in the study of nuclear disintegration and scattering investigations, and also in cosmic ray research. For the last type of work the photographic plate acts as an integrating Wilson's chamber, by means of which cosmic ray processes of very rare occurrence can be conveniently investigated.

As an introduction, I propose to give a short account of the constitution of the photographic emulsion, the action of light radiation in producing developable latent image, and the generally accepted theoretical interpretation of the known properties of the emulsion towards light radiation. The action of ionising particles in producing latent image in photographic emulsion has not yet been so thoroughly studied. With the growing importance of the photographic emulsions for such investigations, new types of plates are being placed in the market by Agfa, Kodak and specially by Ilford and Co. It is a pity that we have no firm manufacturing photographic emulsions in this country with whose cooperation it would have been possible for us to investigate the action of moving charged particles in producing latent images and also in making new emulsions to suit the changing requirements of research. For example, it has been found that the dye pina-kryptol yellow, which is a desensitiser of the action of light on photographic emulsions, increases the sensitivity of the latter to the detection of protons, and no explanation of this effect has yet been found.

A photographic emulsion consists of a suspension of tiny AgBr crystals with a small percentage of AgI in gelatine. In ordinary emulsions there are about 10^9 grains per cm.^{2} of plate area, and the average size of the grains vary from 0.1×10^{-8} cm.^{2} for slow speed positive emulsions to 1.0×11^{-8} cm.^{2} for fast negative emulsions. The grains are usually flat plates of triangular and hexagonal shape, and their thicknesses are about 1/10 of their diameters. It is found that the sensitiveness of the emulsion to light is increased by the presence of a minute quantity of Ag_2S in it, and it can be further increased by the process of ripening. It is supposed that on the surface of each AgBr grain is a sensitive spot containing either a small amount of Ag_2S or a minute silver speck formed during the process of ripening. The latent image is formed during the exposure to light by a sufficient number of silver atoms being deposited round this speck.

The mechanism by which the silver atoms are deposited is conceived according to the generally accepted theory of Gurney and Mott, as follows. Each quantum of light absorbed raises one of the attached electron in Br^- ions to the conduction level of the AgBr crystal, where it begins to migrate until it gets finally trapped on the sensitive spot on the grain. The accumulation of a few such electrons on the spot produces a strong local field in which some of the Ag^+ ions in the ionic AgBr crystal begin to migrate and get finally attached to the spot as neutral Ag atoms. A mechanism is also proposed according to which the Br^- ions released by the production of neutral Ag atoms can ultimately escape from the surface of the grain. As to the size of the latent image it is found that the number of light quanta required to be absorbed for their formation vary with the grains; on an average about 50 per cent of the grains become developable by the absorption of 50 light quanta by each. We conclude that the latent image in any grain of AgBr is a speck of silver containing at least 50 atoms.

It is found that these photographic emulsions also react to the action of ionising particles like α-particles, protons, deuterons and even electrons. The effects observed fall under two categories—(*i*) the density of blackening produced on photographic emulsions exposed normally to a corpuscular beam, in which the density-exposure relation for different kinds of charged particles are studied. Investigations have been made as to how far the Reciprocity law holds for irradiation by charged particle and (*ii*) the number of grains developed along the tracts of the charged particle in the emulsion. Two reports are available which summarise the results so far obtained, the first one by H. Wambacher, 'Action of corpuscular radiation on photographic emulsion,' *Zeit. f. Wiss. Phot.*, **38**, 38, 1939, the other is a report by T. R. Wilkins 'The response of photographic materials to Atomic particles,' *J. of App. Phy.*, **11**, 35, 1940.

The results obtained have been summarised by Wambacher as follows :—

1 X-ray quantum ($\lambda = 0.5$Å)—on an average develops one grain of AgBr (total number of Ag atoms released 1000)

1 α-particle from Ra ($6.10^6 eV$)—10-15 grains of AgBr (total number 50,000 Ag atoms)

6-8 β-particles (10^5-$10^6 eV$)—1 AgBr grain

1 electron ($10^4 eV$)—2 AgBr grains

10^4 positive-ray particles (800 eV)—one AgBr grain.

The most carefully investigated effect of corpuscular radiation on photographic emulsion has been with α-particles. Each α-particle produces on an average 2-3 thousand Ag atoms per AgBr particle struck, it thus, as experimentally proved, blackens every particle passed through by it.

The action of β-particles and positrons on photographic emulsion is not clearly known. Slow electrons (energy of order $10^4 eV$) may ionise the AgBr grain on its path but owing to their small mass they are easily scattered and therefore do not form a linear deposit of blackened grains; further they give rise to fluorescent radiation, by collision both with the emulsion and its glass backing, which blackens the emulsion. On the other hand fast electrons (energy 10^5-10^6 eV) do not sufficiently ionise the AgBr grains so that their tracks cannot be made visible on photographic emulsions.

Fast protons produced by the recoil of α-particles with hydrogen have also been shown to produce definite ionisation tracks. These investigations are due to Taylor and to Blau and Wambacher, and as the latters' investigations have been the starting point of our own work, more attention will be given to it.

The technique of the method used to see the tracks of individual high energy particle like α-particle, deuteron or proton is as follows. The photographic plate exposed to the radiation is developed and examined under a high-power microscope. The quantities to be measured are the length of the tracks on the emulsion usually given in units of $\mu(10^{-4}$ cm.). It is found that the emulsions have a density of about 2.8, and one cm. of length of track in air is equivalent to about 7μ length in the emulsion. The other important factor to be noticed is the quantity known as mean grain distance (m.p.d.) along a track = $\frac{\text{length of the track in } \mu}{n-1}$, where n is the number of developed grains on the track. Both these quantities depend upon the charge and energy of the ionising particle.

The suitability of a photographic emulsion for this kind of work depends upon that

(*i*) the emulsion must be as fine-grained as possible so as to have the maximum number of developed grains along the track of an ionising particle ;

(*ii*) it should be as free from background fog as possible, and the development should be so conducted as to minimise the production of such fogs. The effect of background fog is to prevent the clear discernment of the tracks of ionising particles, specially those in which the grain distance is large ;

(*iii*) it is found that different types of emulsion are sensitive to one or more kinds of ionising particles, *e.g.*, Ilford R_1 plates only record tracks of α-particles, while the R_2 plates record in addition the tracks of slow protons. Blau found that certain emulsion like Imperial process plates when bathed in a solution of pinakryptol yellow (a desensitiser in ordinary photographic process) the tracks due to the passage of protons are greatly lengthened. Similar treatment of Ilford R_2 plate by Kuerti and Wilkins led to the proton tracks on them being increased by 8 or 9 times in length as that in untreated plates, and the tracks so obtained corresponded in full to the range of the proton in the emulsion. But the best results were obtained by Blau and Wambacher by using Ilford New Halftone plates, which for purpose of cosmic ray investigations were used with a film thickness of 70μ (ordinary R_2 plates have a thickness of 14μ).

The m.p.d. for different particles found with these plates are given below :

Particle	Blau & Wambacher m.p.d.	Bose & Chowdhury
Particles from Th. C range 8.62 cm. in air	$1.42\ \mu$	$1.8\ \mu$
Proton range 5.8-29 cm 29-85 cm.	$1.5\ \mu$ $1.56\ \mu$	$2.6\ \mu$

i.e., according to Blau and Wambacher, up to energies of 10 MeV the mean particle distance of α-particles and protons are independent of their energies. Our results are slightly different and may be attributed to some difference in the composition of the emulsion supplied to us. Such plates were exposed in their original packing at Hafelecker (230 m) and kept there for four months at the temperature 15° C In an area of .507 cm^2, when only tracks of length greater than 10 cm. air were counted. Blau and Wambacher found the number to be 85. They consisted of 29 tracks with lengths greater than 1 metre of air, one of length $6\frac{1}{2}$ metres and another of 12 metres. The mean particle distance varied between 1.37μ and 5.7μ. It was improbable that with the exception of two with m.p.d less than 1.5μ they were due either to α-particles or β-particles or positrons.

The conclusion was drawn that they are due to fast protons. This conclusion tacitly implies that though, up to energies of 10 MeV, the mean grain distance of the proton tracks was a constant, for higher energies however the m.p.d- increased. The authors tried to build up an energy calibration curve on the line of Braggs Ionisation curve for these particles. For this curve use was made of the fact that along different portions of long tracks the grain distances were found to decrease continuously from one end of the track to the other, this direction of decrease would correspond to the direction of diminution of velocity of the ionising particle. This calibration curve was used to determine the energy of short-range tracks on the emulsion which had large values of m.p.d. It was shown that in many such tracks the direction of traversal of the ionising particle was inclined to the plane of the emulsion surface and so only a short range of the track was continued inside the emulsion. These tracks were assumed to be due to protons, which were supposed to be produced in the material of the emulsion by recoil from the fast primary neutrons in the cosmic rays. As will be reported later, our own investigations lead to the conclusion that the tracks with m.p.d. $> 3\mu$ are due mostly to mesotrons. In addition to these single tracks, 60 cases of nuclear disintegration were observed, giving rise to multiple star like tracks radiating from a centre (up to 12 in member). Out of 31 stars which were measured the energy of disintegration in four cases was 100 MeV, the emitted particles being assumed to be prtoons. Such emission of protons (with emission of an equal number at least of non-ionising neutrons) can take place according to the nuclear evaporation process (on the liquid drop model), If the particle has a range R(p) in the given medium

$$R = \frac{mc^2}{a}\left[\frac{2+\left(\frac{pc}{mc^2}\right)}{\sqrt{1+\left(\frac{pc}{mc^2}\right)^2}} - 2\right]$$

where *a* is a constant of the medium.

For low values of p, $R = \frac{b}{Z'^2}\frac{E^{\frac{3}{2}}}{\sqrt{M}}$; if the energy E is expressed in MeV, and M the mass of the particle in proton unit, then for air $b = \frac{1}{3}$.

The average deflection θ of such a particle due to multiple scattering is given by $\theta = (19.5 - 3.1\log_{10} Z)^{\frac{1}{2}} e\frac{ZZ'e^2\sqrt{Nt}}{E}$.

In a Wilson chamber, for ionising particles of energy between $10^7 - 10^8$ eV, the ionisation of a mesotron will be much stronger than that of an electron, and the mass of the former can be derived from any two of the following measurements, range (if the particle track ends inside the chamber), ionisation density, and curvature in a magnetic field.

Now let us consider the application of these formulas to the tracks of the ionising particle on photographic emulsions. According to Wambacher the composition of a silver bromide emulsion (probably Ilford Halftone) is as follows

H	C	N	O	S	Br	Ag
15,	9.6,	2.8,	3.5,	0.1,	1,	1

Its density is 2.89 and it has an average atomic number $Z = 6.2$ and the number of atoms per c.c. comes out to be 1.4×10^{23}. From the ionisation loss formula, knowing the velocity and charge of the ionising particle, we can calculate the average number of ions produced per unit length. Assuming that the silver bromide crystallites are of uniform size, then theoretically it is possible to calculate the number of electrons produced in each grain; if this number is above the minimum number n_0 necessary to develop all the silver bromide grains, then all of them are developed (50 to 100 atoms of silver require to be deposited in grains of silver bromide by light in order that 50% of the grains may be developed). According to Blau, each α-particle on an average produce 2000-3000 silver atoms per AgBr particle struck, and therefore as found experimentally up to α-particle from Th C′ (energy 9.7 MeV), the mean particle distance remains constant and equal to the distance between the silver bromide crystals in the emulsion.

In the case of recoil proton tracks on Ilford Halftone emulsion, Blau and Wambacher find that up to a range of 100 cm. air, the m.p.d. is 1.54μ as against 1.4μ for α-particle. While from our own records we find that the m.p.d. increase from 1.8μ for α-particle to 2.6μ for protons. We find therefore for recoil protons even for ranges up to 60 cm. air, not all the silver halide grains along their tracts are affected. To account for this we suppose that if the average number of Ag atoms deposited per grain of AgBr by proton be $\bar{n}$ and it is less than n_0 the minimum number per grain required to develope it, than the probability that a grain is developed is $P(n_0)=\frac{n_0^{-n}\,e^{-n}}{n_0!}$; this integrated over the limits n_0 to ∞ and mutiplied by the number of AgBr grains per unit length of emulsion will give the number of grains which will be deposited per unit length of the track. There are many difficulties in the way of solving this problem; for one thing the size of the grains is not uniform, nor are they all at the same stage of ripeness, *i.e.*, different grains will require the deposition of different number of silver atoms to enable them to act as latent image.

Since it is not possible to deduce from the general ionisation formula, the relation between the charge and velocity of a particle and the number of silver grains deposited per unit length along its track in a photographic emulsion, we may proceed to attack the problem in a semi-empirical way as suggested by Helen & Wilkin. According to them due to the motion of charged particle, each of the grains receives an impulse $I=\int F dt \sim \frac{Z'e^2}{\rho^2}\cdot\frac{1}{v}$ approximately, where ρ = the distance between the moving particle of charge $Z'e$, and an electron in the silver halide grain and v is its velocity. If this impulse is greater than a critical value I_0, then a sufficient number of electrons is set free in the grain to produce a latent image. Thus all the silver halide grains n within a volume $\pi\rho^2.1$ will be affected where $n \sim \pi\rho^2 \sim \frac{Z'e^2}{v}\cdot\frac{1}{I_0}$. Using the formula giving the range of a charged particle as function of its mass energy and charge, it can be shown that if n_α, n_p and n_D are the number of silver grains developed per unit lengths of the tracks of α-particle, proton and deuteron of the same range,

then $\frac{n_\alpha}{n_p}=2$ while Helen & Wilkins find experimentally the value 1.7

and $\frac{n_D}{n_p}=1.25$,, ,, ,, 1.4

There is thus only a very approximate agreement with experimental results. According to this formula the number of grains, developed per unit length of a moving charged particle is proportional inversely to the velocity of the particle. This formula is not even approximately correct. If a proper correlation between the values of n and v for any kind of charged particle can be found, then the mass of that particle can be determined from it and from the multiple scattering suffered by the same particle traversing through a known length of the photographic emulsion. The multiple scattering is proportional inversely to the energy E of the particle.

The importance of this result lies in the fact that many of the highly ionising tracks observed in Ilford Halftone plates exposed by us to cosmic radiation have been found to be curved. As will be shown just now, it has enabled us to decide that the particles responsible for them must have a mass lower than that of protons, and since fast electrons do not produce such tracks on photographic emulsions, these tracks must be due to mesotrons.

I shall next proceed to give an account of our own investigation on cosmic rays using the photographic plates as detectors. We have followed Taylor's procedure of keeping R_2 plates at high altitudes, half of each plate being treated with a solution of a salt of a heavy element like Uranium, Lead, Bismuth, Samarium, and Rubidium. Like Taylor we have obtained positive results of disintegration of Samarium nucleus under the action of some component of cosmic rays. No definite results could be obtained with Uranium, due to the large number of secondary particle tracks shown on the plates, resulting from the natural disintegration of the Uranium nucleus and of its products. The investigations with the other substances are being continued, no definite results have yet been obtained.

We have also in another series of investigations followed Blau and Wambacher in keeping untreated Ilford Halftone plates in paper cartons exposed to cosmic radiation. The plates are kept at three different elevations—Darjeeling (Mayapuri Research Station, elevation 7,000 ft.), Sandakphu (Dak Bungalow, 12,000 ft.) and Phari Jong Post-Office (14,500 ft.). These plates were kept vertically standing on their longside, under the following conditions (*i*) Darjeeling exposed to air, (*ii*) Sandakphu, exposed to air, kept under 20 cm. of water, under 5.5 cm. of lead, (*iii*) Phari Jong exposed to air, kept vertical and flat.

From the plates kept at Darjeeling and Sandakphu, information has been obtained on (*a*) the relative intensity of the track producing rays at these two places (*b*) the relative absorption in 20 cm. of water of the radiation at Sandakphu and in the air mass between Sandakphu and Darjeeling which has a mass of 140 gm./cm.^2 (*c*) the possibility of production of doubly charged proton. According to Bhabha's theory the following reaction is possible: $P+P \rightarrow P^{++}+N$ and it can take place when a fast proton of energy greater than 35 MeV traverses 45 cm. of water.

The tracks which have been obtained on these plates consist of single and multiple tracks. The number of different kinds of tracks, obtained in the different plates is given in Table II. The last columns give the frequency of single, double, etc. tracts on the given plate areas.

TABLE II

Place	Time of Exp.	Area of plate	Track No.						
			$_1^{le}$	$_2^{le}$	$_3^{le}$	$_4^{le}$	$_5^{le}$	$_6^{le}$	$_7^{le}$
Sandakphu (air)	150 days	1.10 cm.^{2}	87	18	18	18	14	2	1
Sandakphu (water)	202 ,,	1 05	60	8	8	5	4		
Darjeeling (air)	150 ,,	1.00	20	5	19	10	3	2	one burst of 13 tracks

Many of these tracks are curved, and such curved tracks also form part of the multiple star tracks. We shall first confine our attention to the single tracks shown in the plates kept at Sandakphu under air and under 20 cm. of water. In Table III such tracks are collected, in the last column of which the energy of the particles as calculated from the multiple scattering formula of Williams is given. For comparison similiar data for fast proton tracks are given under C. They are produced by the recoil of hydrogen atom in the photographic emulsion by fast neutrons produced by a tube containing Ra and filled with Be powder. Between the source and the photographic plate a block of 10 cm. lead was kept to cut off γ-rays.

TABLE III

A. Sandakphu (Air) Track No.	Total air length.	m.p.d.	No. of curved tracks	Total angle of scattering	Energy MeV
1-22	380 cm.	5.5	4	19°	1.91
23-45	356 cm.	4.2	9	57°	0 61
46-47	395 cm.	3 4	12	61°	0.61
78-87	107 cm.	2.7	2	12°	
B. Sandakphu (Water)					
1-43	411.0 cm.	4.2	9	55°	0.69
	128	2.4	2	16°	1.31
C. Recoil proton	1111 cm.	2.6μ	2 single scattered 1 slightly curved		

From the above table the following inferences can be made (i) if the tracks found on the plates exposed to cosmic ray were due to protons, then those with larger values of m.p.d. (*i e.* $> 2.6\mu$ of proton under C) should possess higher energies, and since the multiple scattering suffered by them are inversely proportional to their kinetic energies, they should be less scattered than the recoil protons shown in C. Actually they are more scattered, and since these particles cannot have less than one unit of charge, their mass must be less than that of proton. Further these tracks cannot be due to electrons, *they must therefore be due to mesotrons.* That is, the particles responsible for tracks with large m.p.d. obtained both by Blau and Wambacher and ourselves in Ilford Halftone plates are principally mesotrons and not protons. It is of further interest to note that the tracks with low m.p.d. on the cosmic ray plates (2.7-2.4μ) have large energies. This result can be satisfactorily explained on the assumption that the particles responsible for them contain a large proportion of protons, produced by recoil from neutrons contained in the cosmic rays

The next point we shall consider is the relative absorption of the primary cosmic radiation responsible for the production of the tracks in air and in water.

In Table IV is given the number of tracks observed in photographic plates kept at Sandakphu and at Darjeeling under different conditions. As a measure of the energy of the cosmic radiation responsible for the production of these tracks, we have taken simply the number of tracks recorded on unit area of the plate in a given time. This is permissible since if these tracks are due to mesotrons, their energy of creation is of the order 10^8 eV, which is very large compared to their kinetic energies. From this count we have excluded tracks in which the m.p.d. is less than 2μ as experience shows that such tracks are usually due to α-particle contamintaions.

TABLE IV

	Plates kept under	No. of tracks per cm^2/100 days	No. of tracks absorbed in	Ratio of absorption
Sandakphu.	(i) air	165	20 gm. of water 98	
	(ii) 20 cm. water	67	140 gm./cm.^{2} of air 61	1.6
Darjeeling	(iii) air	103		

We find that the rays responsible for the production of tracks on the photographic plates are more strongly absorbed in water than in air, *i.e.*, they are chiefly neutrons. This conclusion is supported by the observations of Heitler and his fellow workers who kept similar Halftone plates at Jungfraujoch (13,400ft) under different thicknesses of lead. The number of tracks observed on the plates was a maximum under 1.2 cm. of lead, and it slowly falls down near to its value in air, at under 12 cm. lead. They draw the conclusion that the responsible constituents of the cosmic ray consist of two portions, one easily absorbable and the other very little absorbable in lead, *i.e.*, they consist partly of photons and partly of neutrons. Our own plates kept under lead were found fogged on developement and so could not be utilised. Reverting to our own results, we can calculate from the following considerations the relative energy loss of fast neutrons which are responsible for the creation of single and multiple mesotron showers in the given masses of air and water. A neutron, suffering an elastic collision with an atom of mass M, looses on an average 2/M of its kinetic energy, *i.e.*, it requires M/2 collision to produce the same loss of energy as collision with a hydrogen atom. On calculating the number of equivalent hydrogen-like collisions in the given masses of water and air, the ratio of hydrogen-like collisions comes out to be 1.7, which is very near to the observed value of 1.6.

The agreement between the two (if not accidental) can be made plausible on the following assumptions : (i) the rate of production of such high energy neutrons in the air mass between Sandakphu and Darjeeling are very few compared to the number present in the original beam (ii) the cross-section for elastic scattering is very large compared to that for mesotron production (iii) on an average they do not suffer more than one hydrogen-like collision in the given masses of air and water.

TABLE V

Pair Tracks No.	Total length	m.p.d.	No. of curved tracks	Total angle of scattering	Mean angle between pair
1-18	528 cm.	$4.6\ \mu$	8 (in one pair both tracks are curved)	42°	17°

In Table V data for 18 pair tracks found on the plate at Sandakphu under air is given. From the relation between track lengths m.p.d. and total angle of scattering, there can be no doubt that these pairs consist of mesotrons. The angle between the pairs vary from 6° to 35°, with a mean value of 17°. It is interesting to apply to these pairs the consideration used by Wentzel to limit the angular spread of pairs arising out of the interference of a wave packet of energy E scattered over an obstacle of linear dimension a

$$\theta \lesssim \frac{\lambda}{2\pi a} \lesssim \frac{hc}{2\pi a E}\ ; \text{ here } E = \text{total energy} \backsim 2 \times 10^{8}\ \text{eV}\ ;\ \theta = 17^{\circ}\ ;$$

the value of a comes out to be 2.07×10^{-13} cm. which is of the same order as the electron radius 2.8×10^{-13}. It is difficult to say whether any physical significance can be attached to this quantity.

Since in the other higher multiple tracks the m.p.d. of the tracks also vary between 6μ and 2.5μ, and some of them also appear curved, it is permitted to infer that they are all of mesotron character. The detailed examination of these multiple star tracks is being carried out.

The conclusion can be drawn from our investigation that by the interaction of one or more high-energy components of the cosmic radiation (principally neutrons) with atoms in the photographic emulsion multiple mesotron showers are produced. This conclusion appears to be important since, according to the classical theory of mesotron proposed recently by Bhabha and later taken up by Heitler, the scattering cross-section of mesotrons of energy 10^8 eV by proton or neutron is of the order 10^{-27} to 10^{-28} cm.[2] This is in agreement with the meagre experimental data of J. G. Wilson ; there is no place however for mesotron shower production according to this theory. According to the theory developed by Heitler this cross section remains a constant over a large range of energy. In Bhabha's later developement of the theory of mesotron with a spin, however, the cross-section has a maximum in the region of energy 3.2×10^8 eV. Whether, the sudden increase of scattering cross-section in this region can lead to a process of multiple mesotron shower generation is not clear. A recent theory of Heisenberg appears to give a reasonable picture of multiple mesotron shower production due to impact of uncharged particles on protons and neutrons. It is also free from certain of the theoretical objection raised against the older quantum theory of scattering of mesotron. If the conclusions I have drawn from our photographic records are valid and are further verified by later investigations, then this method can produce experimental evidence of a type of interaction between matter and certain constituents of cosmic radiation, not readily available by other methods. The photographic plate is specially suited to record processes in which protons, mesotrons, α-particles are produced over comparatively low range of energy, *viz.*, in the region of 10^6 eV for α-particles and protons. For this region and for these types of particles the method is superior to the Wilson Chamber apparatus.

We have made a preliminary search for the existence of doubly charged protons, on the plate kept at Sandakphu under 20 cm. of water. As stated earlier, such particles are expected to be created when fast protons of energy greater than 3.5×10^7 eV traverse 45 cm. length of water. Our plate was kept exposed for 202 days and we looked for tracks with m.p.d. between 1.7μ to 2.0μ and of range greater than 10 cm. of air, which is the length of the highest energy particle tracks due to Th C$'$. In an area of 1.05 cm.^{2} no such track has been observed. The investigation is being further continued.

We can summarise the results which have been obtained from a study of cosmic radiation using Ilford Halftone plates as follows :

(*i*) Blau and Wambacher find long single tracks and star-like multiple tracks on such plates in which the m.p.d. vary from 1.37μ to 5.7μ. These tracks are assumed to be due to protons, produced in the case of single tracks by the recoil of protons in the emulsion with fast cosmic ray neutrons. The star-like tracks represent the products of nuclear explosions (presumably of the evaporation type), in which both protons and neutrons are emitted, and of which only the former are recorded.

(*ii*) Heitler and his co-workers only count the number of tracks which appear in such plates kept under different thicknesses of lead plates at Jungfraujoch. They conclude that the components of the cosmic ray responsible for the heavy-ionisation track are partly photons and partly neutrons.

(*iii*) Bose and Choudhury find from the multiple scattering of these tracks that they are principally due to mesotrons, whose energy lie in the range 10^5-10^6 eV. From the relative absorption in water and air the conclusion is drawn that the fast neutrons in the cosmic ray are principally responsible for the creation of mesotrons either singly or in a multiple process.

The data so far collected allow only qualitative conclusions to be drawn. It can be expected that accumulation of a larger amount of data will allow certain quantitative conclusions to be drawn (*i*) on the energy distribution and the relative proportions of photons, neutrons and other possible constituents in the cosmic ray which produce mesotrons by multiple processes of the type envisaged by Heisenberg, (*ii*) on the cross-section for single scattering and for shower production, (*iii*) on the existence of doubly charged protons and antiprotons which according to Bhabha can be created during interaction between protons and protons $P + P \rightarrow P^{++} + N$ and between neutrons and neutrons $N + N \rightarrow P^- + P^+$.

It is imperatively necessary that further investigations on the formation of latent images by the action of moving charged particles in photographic emulsions is undertaken. Without such investigations it will not be possible to make the photographic emulsion an instrument for accurate quantitative measurement in cosmic ray investigations.

Recently the mass of the particles producing curved tracks on the photographic emulsion has been determined. The theory of the method used as follows—if the unknown particle is mesotron, it is singly charged like the proton. and the assumption is made that both the proton and the mesotron will produce tracks on the emulsion with the same m.p.d., provided they start with the same velocities. Then the ratio of the kinetic energies of mesotron and proton with the same m.p.d. will be proportional to the masses of these two particles. The energy of the mesotron can be obtained from the multiple scattering in the emulsion using William's formula. That of the protons can be obtained from calibration curve connecting the K.E. of proton producing tracks on the emulsion, with the m.p.d. along the tracks. The calibration curve was found, up to energies of 10 Mev, to be a straight line, from which the K.E. of the protons corresponding to the m.p.d. found for cosmic ray particles can be obtained by extrapolation. The following values of the mass of the particles have been obtained in terms of electron mass mo, 173, 149, 158, 153, 167 with mean equal to (160.2 ±4.3) mo, which falls within the range of the best determination of the mesotron. It is expected that the introduction of certain corrections will increase the value of μ by ten per cent. The results have been communicated in a note sent recently to ' Nature.'

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