CAMBRIDGE UNIVERSITY EUGENICS SOCIETY

Paper on "HEREDITY" (comparing methods of Biometry and Mendelism) read by Mr R.A. Fisher, Caius, (Chairman of Committee) at Second Undergraduate meeting of the Society in Mr C.E, Shelley's rooms, C. New Court, Trinity College, on Friday, November 10th 1911, at 8.30 p. m.

In compiling this short paper I have not, needless to say, attempted to touch the whole subject; the inherited character controversy I have omitted altogether, as it may be considered as settled, from the practical point of view, in favour of Weissmann; the further controversies which raged over Weissmann's germ-plasm theory may fairly be left to physiologists, if they think that the discussion was profitable.

I rather regret having made no mention of De Vries mutation theory, or of ~~Johnson~~ Johanssen's remarkable work on past pure lines; the latter I should certainly have included if I could have got at the original papers.

I have almost entirely devoted myself to the two lines of modern research which are of particular interest in Eugenics, that is to Biometrics and Mendelism; and perhaps experts and professionals will forgive the absence of the more complicated details in both branches, if I explain that my object has been to give a fair view of the merits of two methods, whose advocates have shown so little appreciation of the other school.

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Fisher's copy of his 1911 paper on Mendelism and Biometry, with corrections in his own handwriting. (Reproduced in Chapter 2 of Natural Selection, Heredity and Eugenics (ed. J.H. Bennett) Oxford University Press, 1983.) - J.H.B.

HEREDITY.

In speaking of heredity it has become usual to commence by pointing out that we can only speak of heredity in respect of variations, while variation itself is only a partial failure of heredity; but we are not now concerned with this apparent paradox; our problem is merely, - given the parents, predict the children, and we are not even specially concerned with the physiological mechanism by which the latter are determined.

Prediction is a matter of probability; in the case of Mendelian heredity we can with certainty predict the possible types of the children of given parents, and say that these will occur in the familiar Mendelian proportions; and if enough offspring can be obtained the numbers actually approximate to the ratios required by theory. The results of biometric research are much more vague, but ~~as~~ are capable of a much wider application; the probable measurements of particular organs of the offspring can be calculated from those of the parents, and those of the general population, and we have to take a large number of families of similar parents from the same population before the accuracy of the prediction becomes apparent. A single family may differ as widely from the result predicted, as a single offspring in Mendelian inheritance may differ from the rest of its family. Mendelism concerns itself with natural pairs of unit characters, each of which may affect a number of organs and measurements, which are inherited in the simple manner discovered by Mendel; biometry deals with artificial measurements, and applies to them statistical methods which are equally applicable to meteorological or economic data; the only assumption is that a large number of independent causes are acting at random, this explains why their results are only true of populations; in single instances there may be only a small number of independent variables.

I had better begin by outlining the view of inheritance which I have taken up, since I shall be continually using the ideas involved. On this theory the inherited nature of any living creature consists of a large number of Mendelian characters; from the moment the ovum is fertilised the creature is affected by its nurture or environment, so that different creatures with the same inherited nature will manifest every kind of variations from their true type; the independent causes are quite indistinguishable, and will affect the organism in innumerable ways. This variation due to nurture can only be treated by statistical methods; luckily in most cases it appears to be small, and still more luckily it is not inherited.

In case it is not superfluous I shall try to give a sketch of Mendelism. The simplest case is that of the blue Andalusian hen; for years breeders have known that these birds would not breed true; there were always black and speckled white chicks in the broods; if they had taken the trouble to count the number of each, they would have found that half the brood was blue each time, a quarter were black and a quarter white. This is a simple case of segregation; the blue and the speckled white are pure breeds, homozygotes as they are called; when crossed all their offspring are heterozygous blue. Blue crossed with black gives a half blue and a half black; with speckled white a half are blue and a half speckled white. It does not matter what the ancestry of the birds was, the offspring can be predicted simply from the parents.

In most cases the heterozygote is indistinguishable in appearance from one of the pure types; this is then called the dominant, from the old notion that its inheritance was stronger and dominated the weaker or recessive type. A case of this occurs in Mendel's original work on garden peas; starting with short and tall varieties Mendel found that the cross was tall, tallness being dominant, and was astonished to find that these tall heterozygotes gave one offspring in four of the short recessive type.

Perhaps the greatest simplification introduced by Mendel's discoveries is the fact that different pairs of characters or allelomorphs are inherited independently of one another. For instance maize grains may be either white or yellow, yellow being dominant, they may also be either smooth or wrinkled; if a plant heterozygous in both characters be self-fertilised, all four types will appear, and the proportion of yellow grains to white will be the same, that is 3 to 1 among the smooth grains as among the wrinkled. Besides its admirable simplicity this segregation enables a breeder to create new pure strains, for instance starting with a couple of grains, one white wrinkled and the other yellow smooth, you could in a few generations produce white smooth and yellow wrinkled grains which would breed true as long as they were wanted.

A number of Mendelian pairs have already been worked out in the case of men; among animals and plants new and valuable races have been created by combining different qualities. For instance a valuable rust-proof wheat has been obtained by crossing the old rust-proof wheat which gave a poor yield with a wheat which yielded a good crop but was subject to rust. The first cross was heterozygous in both factors, but one sixteenth of its offspring was pure bred in both desirable qualities. Suppose we knew, for instance, twenty pairs of mental characters. These would combine ~~with~~ in over a million pure mental types, each of these would naturally occur rather less frequently than once in a million, or in a country like England may occur in 20,000 generations; it will give some idea of the excellence of the best of these types when we consider that the Englishmen from Shakespeare to Darwin (or choose whom you will) have occurred within ten generations; the thought of a race of men combining the illustrious qualities of these giants, and breeding true to them, is almost too overwhelming, but such a race will inevitably arise in whatever country first sees the inheritance of mental characters elucidated.

A large number of rare defects among men are now known to be Mendelian dominants, colour blindness, ~~trachy~~ brachydactylity[1], and the form of insanity known as chorea, are among these; the inheritance of these is easily traced, since half the offspring of any affected person will be affected[2]; the case of colour blindness is peculiar in being recessive in women. These would all be stamped out in one generation by prohibiting affected persons from pairing. I venture to propound the hypothesis that there are a still larger number of recessive defects, by one or more of which almost everyone is affected;

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(1) See table of trachydactylous family, which I have simplified by omitting the children of normal members, all of whom were normal. I have also disregarded the sex, and the order of births which are recorded in Bateson's book on Mendelism.
(2) Deaf mutism.

I suggest this first to explain the sporadic occurrence of defects in the children of healthy parents. Thus, if a recessive defect existed in one person in a thousand, it would not become apparent unless two such persons were to mate, and then a quarter of their children would be affected; so that we should notice a sporadic defect affecting one in four millions[1]. Secondly, to explain the defects, which are well known to follow inbreeding; if there were a thousand such ~~sere~~ recessive defects in a mixed population, each member would on the average have one. A brother and sister each have a half chance of inheriting each of the defects of their parents; if they are mated the chance that they both have it is one quarter, and the chance of each of their children showing the defect is one-sixteenth. If we knew the proportion of such children, who are in any way defective we could calculate the average number of recessive defects in each healthy member of the population[2]. With cousin marriages the danger is divided by four, each of the two common grandparents contributes its defects, but the chance of each occurring is only one in 64. For uncle and niece the danger is the same as for cousin marriages, having four common grandparents, being one-sixteenth for each of the

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(2) See cases of incest collected.
(1) Deaf mutism.

recessive defects which we are supposed, on the average, to possess[1].

Among animals and plants the number of allelomorphs known to scientists is rapidly increasing; they have been especially successful in solving problems of the inheritance of colour. The case of mulattoes used formerly to be urged against the universal applicability of Mendel's method, but it is now known that crosses of black races with white do not result in a uniform blending of the colours, but that some half breeds are quite black and others nearly white; it is probable that there are several factors involved, but as with other human characters it is unlikely that any difficult problems can be quickly cleared up, owing to the racial and economic difficulties of experimental breeding.

The theory of inheritance on which the biometricians based their researches was framed before the rediscovery of Mendel's laws; the spontaneous variations, which are at any rate partially inherited, are supposed to be capable of taking up any of an indefinite range of values for each organ; by taking a sufficient number of measurements[2], say of human stature, we can construct a frequency curve, showing the number of individuals per million of population, whose heights lie within successive inches of the scale. If, as is the case

(1) The theory I have here suggested requires that a strain free from defects may intermarry to any extent without harm; the successive dynasties of the pharoahs, who habitually married their sisters must have been such strains; marriage with half-sisters would in their case have been the more dangerous course.

(2) See Normal Curve.

with human stature, the measure is determined by a large number of small independent factors, the frequency curve will be of the important normal type, and can be completely specified by knowing the mean value, and the standard deviation, which is the most convenient measure of variability.

Among the beautiful and ingenious contrivances which biometricians have devised, perhaps next in importance comes the correlation table; and here we have a measure of inheritance itself. Suppose the million men, which we measured for the frequency curve, eventually become fathers. Consider the sons of all the men who occupy a given range, say from six feet to six feet one; they also will form a frequency curve; their mean is found to be taller than the general population, showing that there is a positive correlation; it will be shorter than their fathers were, showing a regression towards the mean of the population; actually their mean will be about half way between these two values, and this is found to be true whichever group of fathers is chosen. The coefficient of correlation is then said to be about one half. Coefficients of correlation have been worked out in a large number of cases, between all sorts of characters; the method may of course be applied to different organs of the same individual, and as such, will ascertain the numerical measure of the 'correlation' to which Darwin attached so much importance.

The value of biometrical work is largely due to the fact that the actual evolution of new species in the past is a question of populations, and must have taken place in the way indicated by statistical methods. The synthetic breeding required by Mendelism could never have taken place in a state of nature; the strains would never have become pure, until a slow and continuous selection had long acted on the whole population. Gradually the breed would improve in those qualities which were of importance; the work which a breeder could now do in three generations might take a hundred for the slow haphazard elimination of nature to accomplish.

It has been shown by Karl Pearson, on whose mathematical work the whole science of Biometrics has been based, that ~~the~~ number of pairs of Mendelian Allelomorphs scattered at random in a population would ~~require~~ as the independent arbitrary causes which biometricians require. On this basis he has worked out the coefficient of correlation between parent and child, and finds that it should be one third if dominance is complete, and one half if there is no dominance, i.e. if the heterozygote lies mid-way between the pure races. The coefficient found experimentally is usually about one half, which seems to indicate that the factors which determine the principal measurable quantities are to be regarded as exhibiting no dominance. At first sight this may seem a serious discrepancy from the ordinary Mendelian results, in which dominance is an almost universal phenomenon; but it must be remembered that the majority of these results refer to colour inheritance, which is apparently determined by the presence or absence of some enzyme or ferment, capable of producing the colour; the heterozygote also contains the enzyme; possibly only as a half dose, but this is sufficient to determine that the pigment is produced. It would not be at all surprising if allelomorphs relating to structure showed imperfect dominance, or no dominance at all.

One of the great beauties of biometrical work is the certainty of the results obtained; biometricians avoid all the difficulties of abstract theories, they deal only with observations; and even if their observations are full of small errors, and they probably are, they appear to be able to squeeze truth out of the most inferior data. The probable error can in every case be calculated, and though possible error is unlimited, the probability of large errors can be shown to be very small. I was recently impressed by the potency of the theory of probabilities in this respect; if you put a kettle over a fire it will probably boil; but it is not a certainty, it may freeze; it is true the odds against such an event are very large; but it remains a possibility, or so my "theory of gases" tells me.

It is interesting that Mendel's original results all fell within the limits of probable error; if his experiments were repeated the odds against getting such good results is about 16 to one. It may have been just luck; or it may be that the worthy German abbot, in his ignorance of probable error, unconsciously placed doubtful plants on the side which favoured his hypothesis.

The interest of biometrical work for Eugenists lies in that fact that Francis Galton employed this method, the only one then open to him, to prove that human characters are as strongly inherited as those of animals; and mental characters as much as physical. Karl Pearson has collected data of school children and has established the fact that all the mental characters for which he has data are as strongly inherited as are physical measurements. In his "hereditary genius" Galton treats of mental and moral characters on the assumption, now seen to be fully justified, that intellectual and moral excellence follows the normal curve, or what is known as Quatelet's law; he arranges men in fourteen classes, seven above and seven below the average, lettering them from the centre from A to G. Little "f" and little "g" are insane or idiotic, little "d" and "e" are stupid and often feeble-minded; thence we rise to the bulk of the population lying from c, b, a, A, B to C, which is the level of the ordinary foreman of a jury. D and E are able, resourceful men to whom most of the prizes in life fall. F and G Galton describes as eminent; they contain about one in four thousand of the population. These are the men to whom all advances in thought are due, they produce all the best literature, give us the leading scientists, doctors, lawyers, and administrators: in "hereditary genius" Galton shows how strongly such talents are inherited; and it is of the utmost importance to select such men from whatever class they may be born in, to enable them to rise in the world, to encourage them to marry women of their own intellectual class, and above all to see that their birth-rate is higher than that of the general population. Most of them rise inevitably to a comfortable position; it is natural that they should marry into families of high if not conspicuous ability; but at present, there is no doubt, that the birth-rate of the most valuable classes is considerably lower than that of the population in general, and conspicuously lower than that of the lowest mental and moral class of the population.

Biometrics then can effect a slow but sure improvement in the mental and physical status of the population; it can ensure a constant supply to meet the growing demand for men of high ability. The work will be slower and less complete than the almost miraculous efforts of Mendelian synthesis; but, on the other hand, it can dispense with experimental breeding, and only requires that the mental powers should be closely examined in a uniform environment, for instance, of the elementary schools, and that special facilities should be given to childre of marked ability. Much has been done of late years to enable able children to rise in their social position, still we may as well remember that such work is worse than useless while the birth-rate is lower in the classes to which they rise, than in those from which they spring.

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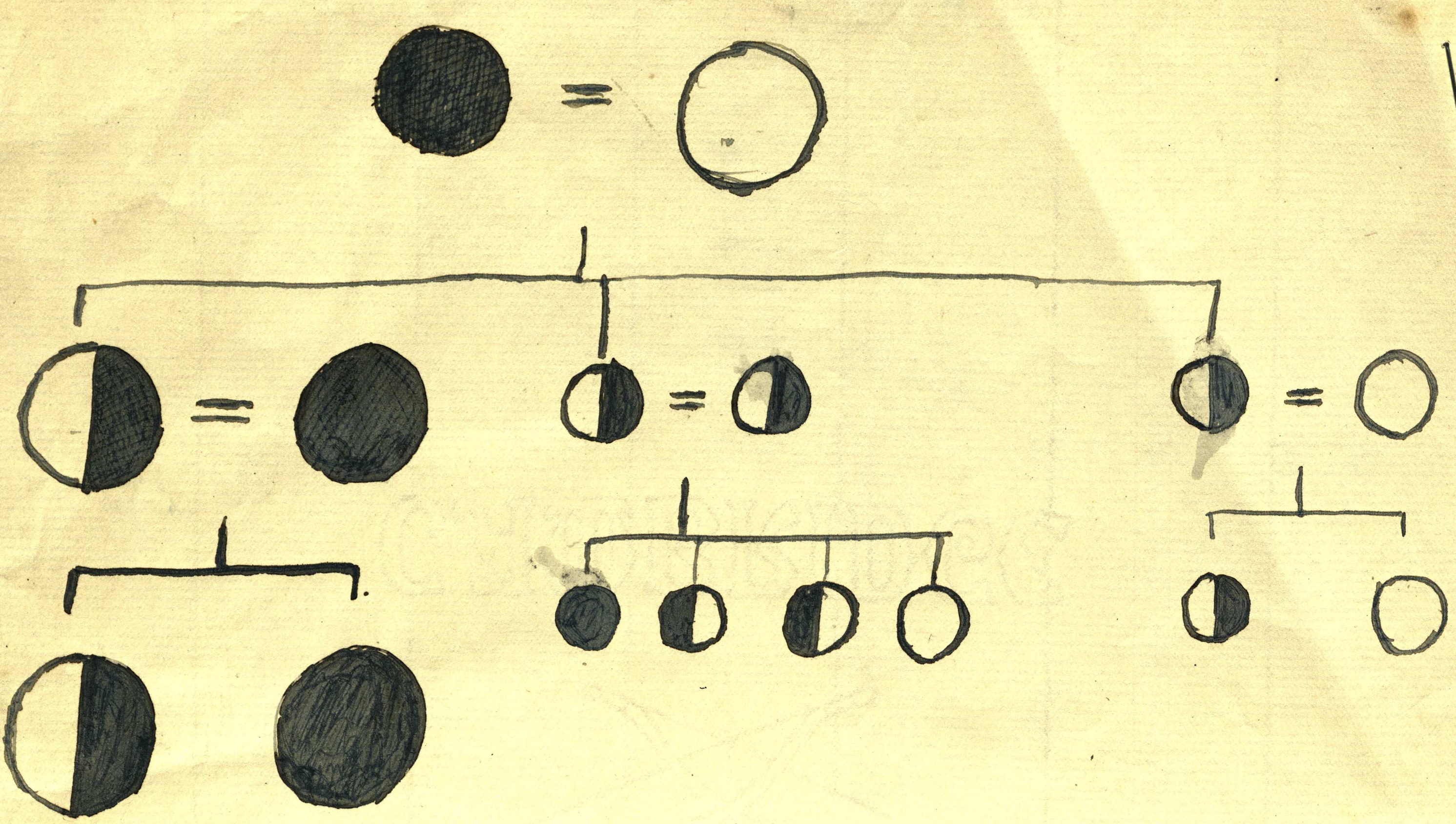
REAL



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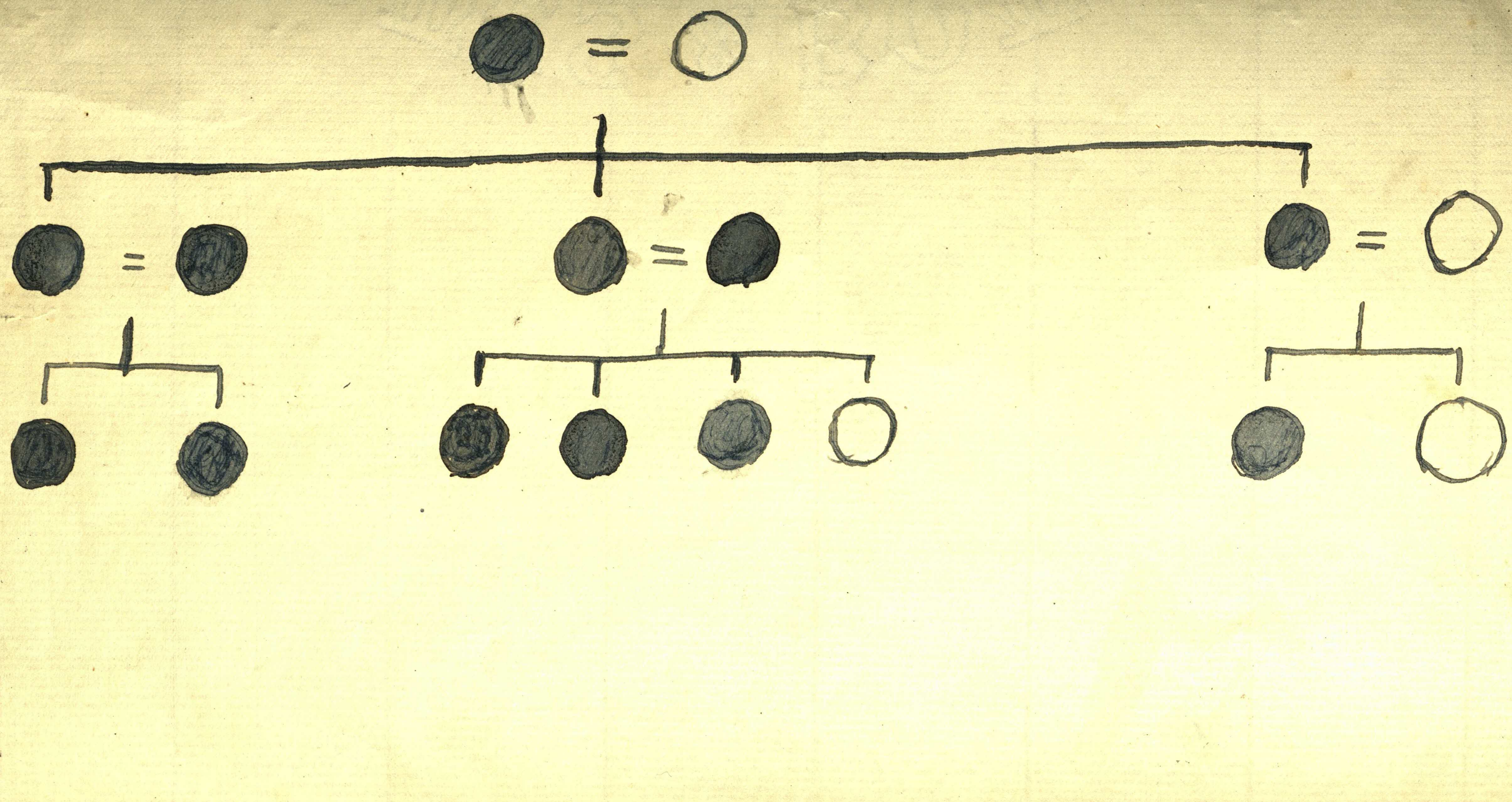

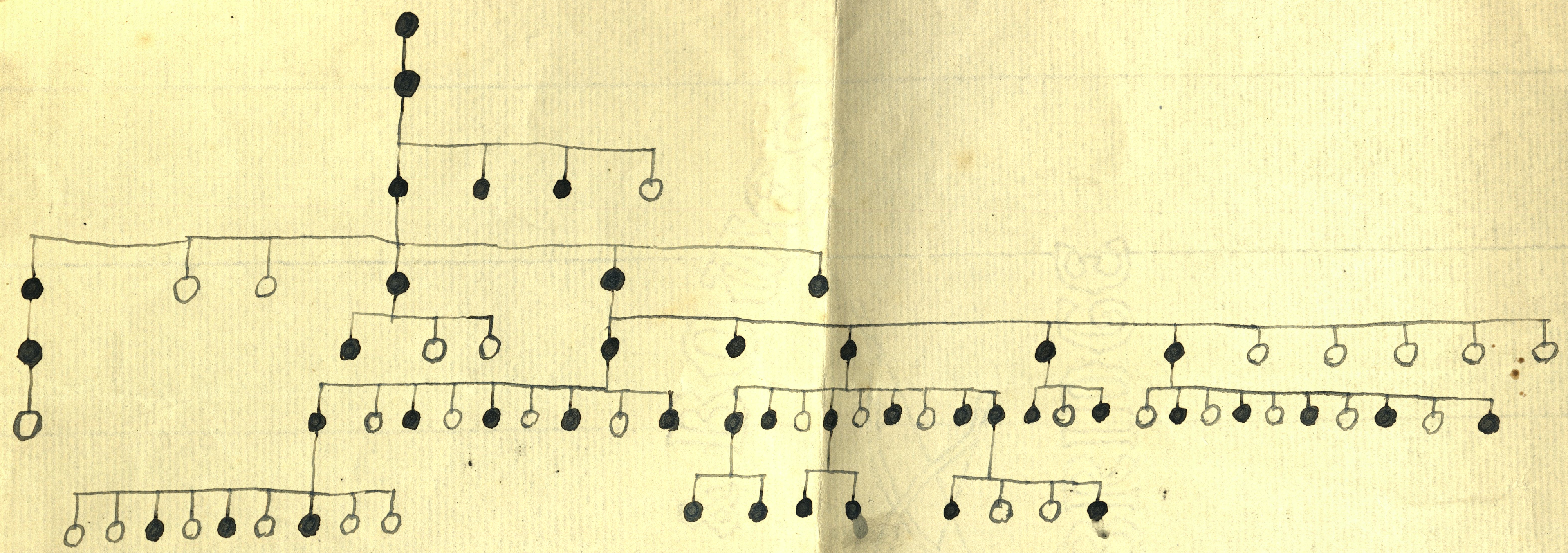

42 affected

32 normal

16 unknown

See Bateson 1909 p215 Fig 28 (JHB)