

**THE INCIDENCE OF ALKAPTONURIA:
A STUDY IN CHEMICAL INDIVIDUALITY**

ARCHIBALD E. GARROD

Physician to the Hospital for Sick Children, Great Ormondstreet,
Demonstrator of Chemical Pathology at St. Bartholemew's Hospital

Garrod, Archibald E. 1902. The Incidence of Alkaptonuria: A Study in Chemical Individuality. *Lancet*, vol. ii, pp. 1616-1620.

Very shortly after the rediscovery of Mendel's work, Archibald Garrod, a practicing physician, determined that Mendelian genes could affect biochemical processes. He called such inherited defects "inborn errors of metabolism" and, on his own, essentially founded biochemical genetics. Like Mendel, he was well ahead of his time, so that his work was largely unnoticed until the later efforts of Beadle and others established the "one gene — one enzyme" hypothesis.

© 1996, Electronic Scholarly Publishing Project

This electronic edition is made freely available for scholarly or educational purposes, provided that this copyright notice is included. The manuscript may not be reprinted or redistributed for commercial purposes without permission.

Garrod, Archibald E. 1902. The Incidence of Alkaptonuria: A Study in Chemical Individuality. *Lancet*, vol. ii, pp. 1616-1620.

THE INCIDENCE OF ALKAPTONURIA: A STUDY IN CHEMICAL INDIVIDUALITY

ARCHIBALD E. GARROD

Physician to the Hospital for Sick Children, Great Ormondstreet,
Demonstrator of Chemical Pathology at St. Bartholemew's Hospital

ALL THE MORE RECENT WORK on alkaptonuria has tended to show that the constant feature of that condition is the excretion of homogentisic acid, to the presence of which substance the special properties of alkapton urine, the darkening with alkalis and on exposure to air, the power of staining fabrics deeply, and that of reducing metallic salts, are alike due. In every case which has been fully investigated since Wolkow and Baumann¹ first isolated and described this acid its presence has been demonstrated and re-examination of the material from some of the earlier cases also has led to its detection. The second allied alkapton acid, uroleucic, has hitherto only been found in the cases investigated by Kirk and in them in association with larger amounts of homogentisic acid.² By the kindness of Dr. R. Kirk I have recently been enabled to examine fresh specimens of the urines of his patients who have now reached manhood and was able to satisfy myself that at the present time even they are no longer excreting uroleucic acid. After as much of the homogentisic acid as possible had been allowed to separate out as the lead salt the small residue of alkapton acid was converted into the ethyl ester by a method recently described by Erich Meyer³ and the

¹ Wolkow and Baumann. 1891. *Z. Physiol. Chemie*. **XV**: 228.

² R. Kirk. 1889. *Journal of Anatomy and Physiology*. **XXIII**: 69; Huppert. 1897. *Zeitschrift für Physiologische Chemie*. **XXIII**: 412.

³ E. Meyer. 1901. *Deutsches Archiv für Klinische Medizin*. **LXX**: 443.

crystalline product obtained had the melting point of ethyl homogentisate (120° C.). Further observations, and especially those of Mittelbach,⁴ have also strengthened the belief that the homogentisic acid excreted is derived from tyrosin, but why alkaptonuric individuals pass the benzene ring of their tyrosin unbroken and how and where the peculiar chemical change from tyrosin to homogentisic acid is brought about, remain unsolved problems.

There are good reasons for thinking that alkaptonuria is not the manifestation of a disease but is rather of the nature of an alternative course of metabolism, harmless and usually congenital and lifelong. Witness is borne to its harmlessness by those who have manifested the peculiarity without any apparent detriment to health from infancy on into adult and even advanced life, as also by the observations of Erich Meyer who has shown that in the quantities ordinarily excreted by such persons homogentisic acid neither acts as an aromatic poison nor causes acid intoxication, for it is not excreted as an aromatic sulphate as aromatic poisons are, nor is its presence in the urine attended by any excessive output of ammonia. However, regarded as an alternative course of metabolism the alkaptonuric must be looked upon as somewhat inferior to the ordinary plan, inasmuch as the excretion of homogentisic acid in place of the ordinary end products involves a certain slight waste of potential energy. In this connexion it is also interesting to note that, as far as our knowledge goes, an individual is either frankly alkaptonuric or conforms to the normal type, that is to say, excretes several grammes of homogentisic acid per diem or none at all. Its appearance in traces, or in gradually increasing or diminishing quantities, has never yet been observed, even in the few recorded temporary or intermittent cases. In cases in which estimations have been carried out the daily output has been found to lie within limits which, considering the great influence of proteid food upon the excretion of homogentisic acid and allowing for differences of sex and age, may be described as narrow. This is well illustrated by Table I, in which the cases are arranged in order of age.

⁴ Mittelbach. 1901. *Ibid.* LXXI: 50.

TABLE I. SHOWING THE AVERAGE EXCRETION OF HOMOGENTISIC ACID

No.	Sex	Age	Average excretion of homogentisic acid per 24 hours on ordinary mixed diet	Name of observers
1	M	2½ years	3.2 grams	Erich Meyer
2	M	3½ years	2.6 grams	A. E. Garrod
3	M	8 years	2.7 grams	Ewald Stier
4	M	18 years	5.9 grams	P. Stange
5	M	44 years	4.6 grams	Mittelbach
6	M	45 years	4.7 grams	H. Ogden
7	M	60 years	5.3 grams	Hammarsten
8	F	60 years	3.2 grams	H. Emlsen
9	M	68 years	4.8 grams	Wolkow and Baumann

The information available as to the incidence of alkaptonuria is of great interest in connexion with the above view of its nature. That the peculiarity is in the great majority of instances congenital cannot be doubted. The staining property of the urine allows of its being readily traced back to early infancy. This has been repeatedly done and in one of my cases⁵ the staining of the napkins was conspicuous 57 hours after the birth of the child. The abnormality is apt to make its appearance in two or more brothers and sisters whose parents are normal and among whose forefathers there is no record of its having occurred, a peculiar mode of incidence which is well known in connexion with some other conditions. Thus of 32 known examples, which were presumably congenital, no less than 19 have occurred in seven families. One family contained four alkaptonurics, three others contained three, and the remaining three two each. The proportion of alkaptonuric to normal members is of some interest and Table II embodies such definite knowledge upon this point as is at present available regarding congenital cases.

⁵ A. E. Garrod. November 30, 1901. *Lancet*: 1481; 1902. *Transactions of the Royal Medical and Chirurgical Society*. **LXXXV**: 69.

TABLE II. SHOWING THE PROPORTION OF ALKAPTONURIC MEMBERS
TO NORMAL MEMBERS IN 9 FAMILIES

No.	Total number of family (brothers and sisters)	Number of Alkaptonuric members	Number of normal members	Observers
1	14	4	10	Pavy
2	4	3	1	Kirk
3	7	3	4	Winternitz
4	2	1	1	Ewald Stier
5	2	2	0	Baumann, Embden
6	1	1	0	Erich Meyer
7	10	1	9	Noccioli and Domenici
8	5	2	3	A. E. Garrod
9	3	2	1	W. Smith, Garrod
Totals	48	19	29	—

The preponderance of males is very conspicuous. Thus, of the 40 subjects whose cases have hitherto been recorded 29 have been males and only 11 females.

In a paper read before the Royal Medical and Chirurgical Society in 1901 the present writer pointed out that of four British families in which 11 were congenitally alkaptonuric members no less than three were the offspring of marriages of first cousins who did not themselves exhibit this anomaly. This fact has such interesting bearings upon the etiology of alkaptonuria that it seemed desirable to obtain further information about as many as possible of the other recorded cases and especially of those which were presumably congenital. My inquiries of a number of investigators who have recorded such cases met with a most kindly response, and although the number of examples about which information could still be obtained proved to be very limited, some valuable facts previously unknown have been brought to light and indications are afforded of points which may be inquired into with advantage regarding cases which may come under observation in the future. In a number of instances the patients have been lost sight of, or for various reasons information can no longer be obtained concerning them. To those who have tried to help me with regard to such cases, and have in some

instances been at great trouble in vain, my hearty thanks are no less due than to those who have been able to furnish fresh information.⁶

The following is a brief summary of the fresh information collected. Dr. Erich Meyer⁷ who mentioned in his paper that the parents of his patient were related, informs me that as a matter of fact they are first cousins. Dr. H. Ogden⁸ states that his patient is the seventh of a family of eight members and that his parents were first cousins. The three eldest children died in infancy; the fifth, a female, has three children, but neither is she nor are they alkaptonuric. There is no record of any other examples in the family. The patient, whose wife is not a blood relation, has three children none of whom are alkaptonuric. Professor Hammarsten⁹ states that the parents of an alkaptonuric man, whose case he recently described, were first cousins. The patient, aged 61 years, has three brothers and the only brother whose urine has been seen is not alkaptonuric. I have learned from Professor Nocchioli¹⁰ that the parents of the woman whose case he investigated with Dr. Domenici were not blood relations. The patient, a twin, who is one of two survivors of a family of ten, states that none of her relations have exhibited the condition. Dr. Ewald Stier¹¹ informs me that the parents of his patient were not related and it is mentioned in his paper that they were not alkaptonuric. Professor Ebstein¹² states that the parents of the child with "pyrocatechinuria" whose case was investigated by him in conjunction with Dr. Willer in 1875 were not related, but I gather that he would not regard this as an ordinary case of alkaptonuria, the abnormal substance in the urine having been identified as pyrocatechin. Lastly, Professor Osler supplies the very interesting information that of two sons of the

⁶ To Hofrath Professor Huppert and to Professor Osler my very special thanks are due for invaluable aid in collecting information, and I would also express my most sincere gratitude to Professor Hammarsten, Geheimrath Professor Ebstein, Geheimrath Professor Fürbringer, Geheimrath Professor Erb, Professor Nocchioli, and Professor Denigès, as also to Dr. F. W. Pavy, Dr. Kirk, Dr. Maguire, Dr. Fletcher, Dr. Erich Meyer, Dr. H. Ogden, Dr. H. Embden, Dr. Mittelbach, Dr. Ewald Stier, Dr. Grassi, Dr. Carl Hirsch, and Dr. Winternitz, all of whom have been kind enough to help the inquiry in various ways.

⁷ E. Meyer. *Loc. cit.*

⁸ H. Ogden. 1895. *Z. Physiol. Chemie.* **XX**: 289.

⁹ Hammarsten. 1901. *Upsala Läkareförenings Förhandlingar.* **VII** 26.

¹⁰ Nocchioli e Domenici. 1898. *Gazetta degli Ospedali.* **XIX**: 303.

¹¹ Ewald Stier. 1898. *Berliner klinische Wochenschrift.* **XXXV**: 185.

¹² Ebstein and Müller. 1875. *Virchow's Archiv.* **LXII**: 554.

alkaptonuric man previously described by Dr. Futcher¹³ one is alkaptonuric. This is the first known instance of direct transmission of the peculiarity. The parents of the father, who has an alkaptonuric brother whose case was recorded by Marshall,¹⁴ were not blood relations. The above particulars are embodied with those of the congenital British cases previously recorded in the following tabular epitome (Table III).

TABLE III. SHOWING THE LARGE PROPORTION OF ALKAPTONURICS WHO ARE THE OFFSPRING OF MARRIAGE OF FIRST COUSINS

A			
Families the offspring of marriages of first cousins			
No.	Total number of family (brothers and sisters)	Number of known alkaptonuric members	Observers
1	14	4	Pavy
2	4	3	R. Kirk
3	5	2	A. E. Garrod
4	1	1	Erich Meyer
5	8	1	H. Ogden
6	4	1	Hammarsten
Totals	36	12	—

B			
Families whose parents were not related and not alkaptonuric			
No.	Total number of family (brothers and sisters)	Number of known alkaptonuric members	Observers
1	3	2	Armstrong, Walter Smith, and Garrod
2	2	1	Ewald Stier
3	10	1	Noccioli and Domenici
4	?	2	Marshall and Futcher
Totals		6	—

¹³ Futcher. 1898. *New York Medical Journal*. **LXVII**: 69.

¹⁴ Marshall. 1887. *Medical News, Philadelphia*. **L**: 35.

C

Families in which alkaptonuria was directly inherited from a parent			
No.	Total number of family (brothers and sisters)	Number of known alkaptonuric members	Observers
1 *	?	1	Osler and Futcher
Totals		1	—

* B 4 and C 1 refer to two generations of one family. No information is forthcoming as to the absence of alkaptonuria in previous generations. Ebstein and Müller's case, which is not included in the table for reasons given above, would raise the number of families in list B to 5.

It will be seen that the results of further inquiries on the continent of Europe and in America confirm the impression derived from the British cases that of alkaptonuric individuals a very large proportion are children of first cousins. The above table includes 19 cases in all out of a total of 40 recorded examples of the condition, and there is little chance of obtaining any further information on the point until fresh cases shall come under observation. It will be noticed that among the families of parents who do not themselves exhibit the anomaly a proportion corresponding to 60 per cent are the offspring of marriages of first cousins. In order to appreciate how high this proportion is it is necessary to form some idea of the total proportion of the children of such unions to the community at large. Professor G. Darwin,¹⁵ as the outcome of an elaborate statistical investigation, arrived at the conclusion that in England some 4 per cent of all marriages among the aristocracy and gentry are between first cousins; that in the country and smaller towns the proportion is between 2 and 3 per cent, whereas in London it is perhaps as low as 1.5 per cent. He suggests 3 per cent as a probable superior limit for the whole population. Assuming, although this is, perhaps, not the case, that the same proportion of these as of all marriages are fruitful, similar percentages will hold good for families, and assuming further that the average number of children results from such marriages they will hold good for individuals also. A very limited number of observations which I have made among hospital patients in London gave results which are quite compatible with the above figures. Thus, among 50 patients simultaneously inmates of St. Bartholomew's Hospital there

¹⁵ G. Darwin. 1875. *Journal of the Statistical Society*. **XXXVIII**: 153.

was one whose parents were first cousins. On another occasion one such was found among 100 patients, and there was one child of first cousins among 100 children admitted to my ward at the Hospital for Sick Children. It is evident, on the one hand, that the proportion of alkaptonuric families and individuals who are the offspring of first cousins is remarkably high, and, on the other hand, it is equally clear that only a minute proportion of the children of such unions are alkaptonuric. Even if such persons form only 1 per cent of the community their numbers in London alone should exceed 50,000, and of this multitude only six are known to be alkaptonuric. Doubtless there are others, but that the peculiarity is extremely rare is hardly open to question. A careful look-out maintained for several years at two large hospitals has convinced me of this, and although the subject has recently attracted much more attention than formerly the roll of recorded examples increases but slowly.

The question of the liability of children of consanguineous marriages to exhibit certain abnormalities or to develop certain diseases has been much discussed, but seldom in a strictly scientific spirit. Those who have written on the subject have too often aimed at demonstrating the deleterious results of such unions on the one hand, or their harmlessness on the other, questions which do not here concern us at all. There is no reason to suppose that mere consanguinity of parents can originate such a condition as alkaptonuria in their offspring, and we must rather seek an explanation in some peculiarity of the parents, which may remain latent for generations, but which has the best chance of asserting itself in the offspring of the union of two members of a family in which it is transmitted. This applies equally to other examples of that peculiar form of heredity which has long been a puzzle to investigators of such subjects, which results in the appearance in several collateral members of a family of a peculiarity which has not been manifested at least in recent preceding generations.

It has recently been pointed out by Bateson¹⁶ that the law of heredity discovered by Mendel offers a reasonable account of such phenomena. It asserts that as regards two mutually exclusive characters, one of which tends to be dominant and the other recessive, cross-bred organisms will produce germinal cells (gametes) each of which, as regards the characters in question, conforms to one or other of the pure ancestral types and is therefore incapable of transmitting

¹⁶ W. Bateson. 1902. *Mendel's Principles of Heredity*, Cambridge.

the opposite character. When a recessive gamete meets one of the dominant type the resulting organism (the zygote) will usually exhibit the dominant character, whereas when two recessive gametes meet the recessive character will necessarily be manifested in the zygote. In the case of a rare recessive characteristic we may easily imagine that many generations may pass before the union of two recessive gametes takes place. The application of this to the case in question is further pointed out by Bateson, who, commenting upon the above observations on the incidence of alkaptonuria, writes as follows:¹⁷ “Now there may be other accounts possible, but we note that the mating of first cousins gives exactly the conditions most likely to enable a rare, and usually recessive, character to show itself. If the bearers of such a gamete mate with individuals not bearing it the character will hardly ever be seen; but first cousins will frequently be the bearers of similar gametes, which may in such unions meet each other and thus lead to the manifestation of the peculiar recessive characters in the zygote.” Such an explanation removes the question altogether out of the range of prejudice, for, if it be the true account of the matter, it is not the mating of first cousins in general but of those who come of particular stocks that tends to induce the development of alkaptonuria in the offspring. For example, if a man inherits the tendency on his father’s side his union with one of his maternal first cousins will be no more liable to result in alkaptonuric offspring than his marriage with one who is in no way related to him by blood. On the other hand, if members of two families who both inherit the strain should intermarry the liability to alkaptonuria in the offspring will be as great as from the union of two members of either family, and it is only to be expected that the peculiarity will also manifest itself in the children of parents who are not related. Whether the Mendelian explanation be the true one or not, there seems to be little room for doubt that the peculiarities of the incidence of alkaptonuria and of conditions which appear in a similar way are best explained by supposing that, leaving aside exceptional cases in which the character, usually recessive, assumes dominance, a peculiarity of the gametes of *both* parents is necessary for its production.

Hitherto nothing has been recorded about the children of alkaptonuric parents, and the information supplied by Professor Osler and Dr. Ogden on this point has therefore a very special interest. Whereas Professor Osler’s case shows that the condition may be

¹⁷ W. Bateson and Miss E. R. Saunders. 1902. *Report to the Evolution Committee of the Royal Society*. (1): 133n.

directly inherited from a parent Dr. Ogden's case demonstrates that none of the children of such a parent need share his peculiarity. As the matter now stands, of five children of two alkaptonuric fathers whose condition is known only one is himself alkaptonuric. It will be interesting to learn whether this low proportion is maintained when larger numbers of cases shall be available. That it will be so is rendered highly probable by the undoubted fact that a very small proportion of alkaptonurics are the offspring of parents either of whom exhibits the anomaly. It would also be extremely interesting to have further examples of second marriages of the parents of alkaptonurics. In the case of the family observed by Dr. Kirk the only child of the second marriage of the father, not consanguineous, is a girl who does not exhibit the abnormality. The only other available example is recorded by Embden. The two alkaptonurics studied by Professor Baumann and himself were a brother and sister born out of wedlock, and as far as could be ascertained the condition was not present in the children of the subsequent marriages which both parents contracted. The patient of Nocchioli and Domenici was a twin, and I gather from Professor Nocchioli's kind letter that the other twin was also a female, did not survive, and was not alkaptonuric. Further particulars are wanting, and the information was derived from the patient herself, who is described as a woman of limited intelligence but who was aware that in her own case the condition had existed from infancy. It is difficult to imagine that of twins developed from a single ovum one should be alkaptonuric and the other normal, but this does not necessarily apply to twins developed from separate ova.

It may be objected to the view that alkaptonuria is merely an alternative mode of metabolism and not a morbid condition, that in a few instances, not included in the above tables, it appears not to have been congenital and continuous but temporary or intermittent. In some of the cases referred to the evidence available is not altogether conclusive, and it is obvious that for the proof of a point of so much importance to the theory of alkaptonuria nothing can be regarded as wholly satisfactory which falls short of a complete demonstration of the presence of homogentisic acid in the urine at one time and its absence at another. The degree and rate of darkening of the urine vary at different periods apart from any conspicuous fluctuations in the quantity of homogentisic acid which it contains. The staining of linen in infancy is a much more reliable indication, especially if the mother of the child has had previous experience of alkaptonuric staining. In

Geyger's case¹⁸ of a diabetic man the intermittent appearance in the urine of an acid which he identified with the glycosuric acid of Marshall was established beyond all doubt, and the melting point and proportion of lead in the lead salt render it almost certain that he was dealing with homogentisic acid. In Carl Hirsch's case¹⁹ a girl, aged 17 years, with febrile gastrointestinal catarrh, passed dark urine which gave the indican reaction for three days. Professor Siegfried extracted by shaking with ether an acid which gave the reactions of homogentisic acid and formed a sparingly soluble lead salt. Neither the melting point of the acid nor any analytical figures are given. After three days the urine resumed its natural colour and reactions.

Von Moraczewski²⁰ also records a case of a woman, aged 43 years, who shortly before her death passed increasingly dark urine, rich in indican, from which he extracted an acid which had the melting point and reactions of homogentisic acid. Such increasing darkening of the urine as was here observed not infrequently occurs with urines rich in indoxyl-sulphate, as Baumann and Brieger first pointed out, and this was probably a contributory factor in the production of the colour which first called attention to the condition. Stange²¹ has described a case in which the presence of homogentisic acid was very fully established, but he clearly does not regard the mother's evidence as to the intermittent character of the condition as conclusive. Zimnicki's²² case of intermittent excretion of homogentisic acid by a man with hypertrophic biliary cirrhosis is published in a Russian journal which is inaccessible to me, and having only seen abstracts of his paper I am unacquainted with the details. Of hearsay evidence the most convincing is afforded in Winternitz's cases.²³ The mother of seven children, three of whom are alkaptonuric, was convinced that whereas two of her children had been alkaptonuric from the earliest days of life this had not been so with the youngest child in whom she had only noticed the peculiarity from the age of five years. This is specially interesting as supplying a link between the temporary and congenital cases. In a somewhat

18 A. Geyger. 1892. *Pharmazeutische Zeitung*: 488.

19 C. Hirsch. 1897. *Berliner klinische Wochenschrift*. **XXXIV**: 866.

20 W. von Moraczewski. 1896. *Zentralblatt für die Innere Medizin*. **XVII**: 177.

21 P. Stange. 1896. *Virchow's Archiv*. **CXLVI**: 86.

22 Zimnicki. 1900. Jeschenedelnik. Abstract, *Zentralblatt für Stoffwechsel und Verdauungs-Krankheiten*. **I**(4): 348.

23 Winternitz. 1899. *Münchener Medizinische Wochenschrift*. **XLVI**: 749. 11

similar case described by Maguire²⁴ the evidence of a late onset is not so conclusive. Slosse's case²⁵ in which, as in von Moraczewski's, the condition apparently developed in the last stages of a fatal illness, completes the list of those falling into the temporary class. Evidently we have still much to learn about temporary or intermittent alkaptonuria, but it appears reasonable to suppose that those who exhibit the phenomenon are in a state of unstable equilibrium in this respect, and that they excrete homogentisic acid under the influence of causes which do not bring about this result in normal individuals. There is reason to believe that a similar instability plays a not unimportant part in determining the incidence of certain forms of *disease* in which derangements of metabolism are the most conspicuous features. Thus von Noorden,²⁶ after mentioning that diabetes occasionally develops at an early age in brothers and sisters and comparatively seldom occurs in the children of diabetic parents, adds that in three instances he has met with this disease in the offspring of marriages of first cousins. In one such family two out of six children, in another two out of three, and in the third the only two children became diabetic at ages between one and four years.

The view that alkaptonuria is a "sport" or an alternative mode of metabolism will obviously gain considerably in weight if it can be shown that it is not an isolated example of such a chemical abnormality, but that there are other conditions which may reasonably be placed in the same category. In the phenomenon of albinism we have an abnormality which may be looked upon as chemical in its basis, being due rather to a failure to produce the pigments of the melanin group which play so conspicuous a part in animal colouration than to any defect of development of the parts in which in normal individuals such pigments are laid down. When we study the incidence of albinism in man we find that it shows a striking resemblance to that of alkaptonuria. It, too, is commoner in males than in females, and tends to occur in brothers and sisters of families in which it has not previously appeared, at least in recent generations. Moreover, there is reason to believe that an undue proportion of albinos are the offspring of marriages of first cousins. Albinism is mentioned by most authors who have discussed the effects of such

²⁴ R. Maguire. 1884. *Brit. Med. J.* **II**: 808.

²⁵ A. Slosse. 1895. *Annales de la Société Royale des Sciences Médicales et Naturelles, Bruxelles.* **IV**: 89.

²⁶ Von Noorden. 1901. *Die Zuckerkrankheit.* 3. Aufgabe: 47.

marriages and Arcoleo,²⁷ who gives some statistics of albinism in Sicily, states that of 24 families in which there were 62 albino members five were the offspring of parents related to each other in the second canonical degree. On the other hand, Bemiss²⁸ found that of 191 children of 34 marriages of first or second cousins five were albinos. In a remarkable instance recorded by Devay²⁹ two brothers married two sisters, their first cousins. There were no known instances of albinism in their families, but the two children of the one marriage and the five children of the other were all albinos. After the death of his wife the father of the second family married again and none of the four children of his second marriage were albinos. Again, albinism is occasionally directly inherited from a parent, as in one instance quoted by Arcoleo, but this appears to be an exceptional occurrence. The resemblance between the modes of incidence of the two conditions is so striking that it is hardly possible to doubt that whatever laws control the incidence of the one control that of the other also.

A third condition which suggests itself as being probably another chemical "sport" is cystinuria. Our knowledge of its incidence is far more incomplete and at first sight direct inheritance appears to play here a more prominent part. However, when more information is forthcoming it may turn out that it is controlled by similar laws. In this connexion a most interesting family described by Pfeiffer³⁰ is very suggestive. Both parents were normal, but all their four children, two daughters and two sons, were cystinuric. The elder daughter had two children neither of whom was cystinuric. A number of other examples of cystinuria in brothers and sisters are recorded, but information about the parents is wanting, except in the cases of direct transmission. In some of the earlier cases such transmission through three generations was thought to be probable, but the presence of cystin in the urine of parent and child has only been actually demonstrated in two instances. In Joel's³¹ often-quoted case it was only shown that the mother's urine contained excess of neutral

²⁷ G. Arcoleo. 1871. *Sull' Albinismo in Sicilia*. See notice in *Archivio per l'Anthropologia*. I: 367,

²⁸ Bemiss. 1857. *J. of Psychol. Med.* X: 368.

²⁹ Devay. 1857. *Du Danger des Mariages Consanguins, &c.*, Paris.

³⁰ E. Pfeiffer. 1894. *Zentralblatt für Krankheiten der Harn-und Sexual-Organen*. V: 187.

³¹ Joel. 1855. *Annalen der Chemie und Pharmacologie*: 247.

sulphur. E. Pfeiffer³² found cystin in the urine of a father and son and in a family observed by Cohn³³ the mother and six of her children shared the peculiarity. As more than 100 cases are on record the proportion of cases of direct inheritance has not hitherto been shown to be at all high and Pfeiffer's first case shows that, as with alkaptonuria, the children of a cystinuric parent may escape. A large majority of the recorded cystinurics have been males. There is as yet no evidence of any influence of consanguinity of parents and in the only two cases about which I have information the parents were not related. Neither has it yet been shown that cystinuria is a congenital anomaly, although in one case, at any rate, it has been traced back to the first year of life. Observations upon children of cystinuric parents from their earliest infancy or upon newly-born brothers or sisters of cystinurics would be of great interest and should in time settle this question. Lastly, it seems certain that, like alkaptonuria, this peculiarity of metabolism is occasionally temporary or intermittent. The so frequent association with cystinuria of the excretion of cadaverine and putrescine adds to the difficulty of the problem of its nature and upon it is based the infective theory of its causation. However, it is possible that, as C. E. Simon³⁴ has suggested, these diamines may themselves be products of abnormal metabolism. Unlike alkaptonuria and albinism cystinuria is a distinctly harmful condition, but its ill effects are secondary to its deposition in crystalline form and the readiness with which it forms concretions. Its appearance in the urine is not associated with any primary morbid symptoms. All three conditions referred to above are extremely rare and all tend to advertise their presence in conspicuous manners. An albino cannot escape observation; the staining of clothing and the colour of the urine of alkaptonurics seldom fail to attract attention, and the calculous troubles and the cystitis to which cystinurics are so liable usually bring them under observation sooner or later. May it not well be that there are other such chemical abnormalities which are attended by no obvious peculiarities and which could only be revealed by chemical analysis? If such exist and are equally rare with the above they may well have wholly eluded notice up till now. A deliberate search for such, without some guiding indications, appears as hopeless an undertaking as the proverbial search for a needle in a haystack.

³² E. Pfeiffer. 1897. *Zentralblatt für Krankheiten der Harn-und Sexual-Organen*. **VIII**: 173.

³³ J. Cohn. 1899. *Berliner klinische Wochenschrift*. **XXXVI**: 503.

³⁴ C. E. Simon. 1890. *Am. J. Med. Sci.* **CXIX**: 39.

If it be, indeed, the case that in alkaptonuria and the other conditions mentioned we are dealing with individualities of metabolism and not with the results of morbid processes the thought naturally presents itself that these are merely extreme examples of variations of chemical behaviour which are probably everywhere present in minor degrees and that just as no two individuals of a species are absolutely identical in bodily structure neither are their chemical processes carried out on exactly the same lines. Such minor chemical differences will obviously be far more subtle than those of form, for whereas the latter are evident to any careful observer the former will only be revealed by elaborate chemical methods, including painstaking comparisons of the intake and output of the organism. This view that there is no rigid uniformity of chemical processes in the individual members of a species, probable as it is *a priori*, may also be arrived at by a wholly different line of argument. There can be no question that between the families, genera and species both of the animal and vegetable kingdoms, differences exist both of chemical composition and of metabolic processes. The evidences for this are admirably set forth in a most suggestive address delivered by Professor Huppert³⁵ in 1895. In it he points out that we find evidence of chemical specificity of important constituents of the body, such as the haemoglobins of different animals, as well as in their secretory and excretory products such as the bile acids and the cynuric acid of the urine of dogs. Again, in their behaviour to different drugs and infecting organisms the members of the various genera and species manifest peculiarities which presumably have a chemical basis, as the more recent researches of Ehrlich tend still further to show. To the above examples may be added the results of F. G. Hopkins's³⁶ well-known researches on the pigments of the pieridae and the recent observations of the precipitation of the blood proteids of one kind of animal by the serum of another. From the vegetable kingdom examples of such generic and specific chemical differences might be multiplied to an almost indefinite extent. Nor are instances wanting of the influence of natural selection upon chemical processes, as for example, in the production of such protective materials as the sepia of the cuttlefish and the odorous secretion of the skunk, not to mention the innumerable modifications of surface pigmentation. If,

³⁵ Huppert. 1896. *Über die Erhaltung der Arteeigenschaften*, Prague.

³⁶ F. G. Hopkins. 1895. *Philosophical Transactions of the Royal Society*. CLXXXVI (B):661.

then, the several genera and species thus differ in their chemistry we can hardly imagine that within the species, when once it is established, a rigid chemical uniformity exists. Such a conception is at variance with all that is known of the origin of species. Nor are direct evidences wanting of such minor chemical diversities as we have supposed to exist within the species. Such slight peculiarities of metabolism will necessarily be hard to trace by methods of direct analysis and will readily be masked by the influences of diet and of disease, but the results of observations on metabolism reveal differences which are apparently independent of such causes, as for example, in the excretion of uric acid by different human individuals. The phenomena of obesity and the various tints of hair, skin, and eyes point in the same direction, and if we pass to differences presumably chemical in their basis idiosyncrasies as regards drugs and the various degrees of natural immunity against infections are only less marked in individual human beings and in the several races of mankind than in distinct genera and species of animals.

If it be a correct inference from the available facts that the individuals of a species do not conform to an absolutely rigid standard of metabolism, but differ slightly in their chemistry as they do in their structure, it is no more surprising that they should occasionally exhibit conspicuous deviations from the specific type of metabolism than that we should meet with such wide departures from the structural uniformity of the species as the presence of supernumerary digits or transposition of the viscera.