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BLOOD-GROUPING AS A TEST OF NON-PATERNITY

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I. INTRODUCTION

Human individuals of any race can be separated into clearly distinguishable groups by means of certain permanent properties of their bloods. These groupings are based upon purely objective evidence as they can be verified by any competently trained person. The factors that determine these blood groups are subject to an orderly inheritance. The objectivity of this verifiable evidence makes it often of decisive value in arriving at a true solution of many medicolegal problems dealing with blood identification, especially those involving non-paternity, *i. e.,* an alleged father may sometimes be shown not to be the parent of a given child.

The purpose of this paper is to describe the processes of reasoning, and give references to the experimental verification of their validity, in such a way that those who without special training in biology have primarily to deal with these problems, the legal profession and the judiciary, may readily appreciate the compelling logic which makes this evidence decisive. Although this usefulness of blood grouping is a relatively recent discovery, yet by 1929, in but five European countries, Schiff (see reference 5) had compiled a series of 5,584 cases in which blood group determinations had been so applied. Such applications have been extremely rare in American courts. This can only be due to the unfortunately slow diffusion of specialized but widely useful knowledge from one profession to another.

Except in very unusual circumstances of isolation, *blood grouping tests can never affirmatively fix paternity on a man,* but they may exonerate him. In order to understand how it is sometimes possible to prove by such tests that a man is *not* the father of a given child, it is necessary to understand the way in which blood groups are inherited. For this an elementary knowledge of the laws of genetics is useful, but it should be emphasized that the facts of inheritance of blood groups are established by tens of thousands of recorded observations. The purpose of introducing genetic theory

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in connection with this exposition is only to make the laws clearer and to fix them in mind.

II. Genetic Principles

Geneticists have shown that the hereditary characters of animals and plants are determined by units localized in submicroscopic structures called "genes." These in turn are supposed to occur in pairs, and to be localized in small but microscopically visible rod-like bodies that occur in the nuclei of the cells of which plant and animal bodies are built up and by which they are propagated. These rods are called "chromosomes," and are actually observed to occur in pairs, in conformity with theory. A chromosome may carry a number of genes. One member of a pair of chromosomes carries at each point of its structure a gene corresponding to the one at that same point in the other member of the pair.

Now, during the formation of the cells concerned in reproduction (sperms and ova), these pairs of chromosomes separate, and each sperm or ovum contains only one of each kind of chromosome, and forms an exception to the general rule that each cell contains a pair of each kind. A figure may assist in making this clear.

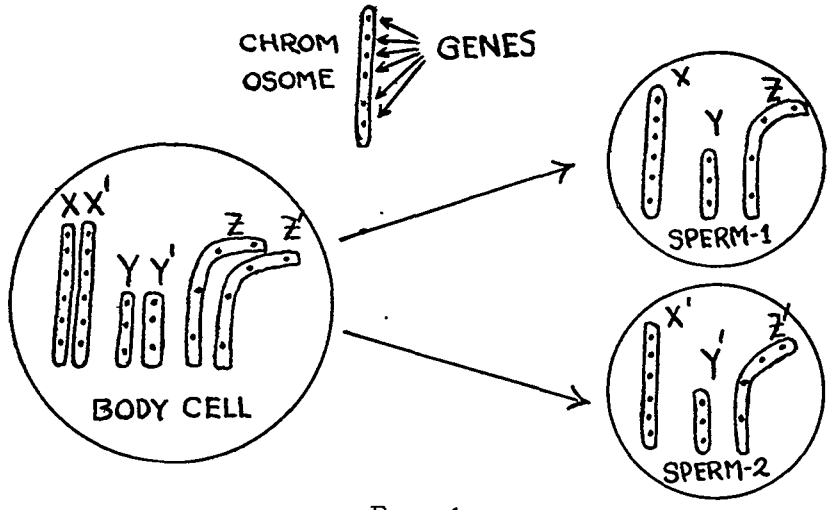

Figure 1.

Diagram illustrating the splitting of chromosomal pairs in the formation of sperms (or ova).

Now, by innumerable experiments on many varieties of living things propagated by sexual reproduction, it has been observed that hereditary characters occur in pairs, whose relationship is shown by breeding experiments, just as this chromosomal theory would demand. The classical human blood groups, discovered by Landsteiner in 1900, are inherited by such a mechanism. They are predetermined by the presence or absence in the chromosomes of two factors (or genes) called "A" and "B". Absence of A and B is indicated by "O." Since each body cell has a *pair* of chromosomes each of which carries or fails to carry one of these factors, an individual's genetic constitution may be represented by AB, AA, AO, BB, BO, or OO, where O represents the *absence* in the chromosome of either the A or B factor at that point. From this it is easy to see that the individual whose genetic formula (genotype) is AB will exhibit both of these factors in his blood (and other) cells, while the AA individual will have only the A characteristic, and the OO will have neither A nor B. The thing that is tested for in the blood cells is not the gene itself, but the substances A and B produced under the specific influence of the inherited genes. It is found that the fact that the AO individual has only one dose, so to speak, of the A factor makes no practical difference, and his blood is routinely indistinguishable, by direct test, from that of the AA individual. This means that we have but four types of blood (phenotypes), O, A, B, and AB, distinguishable from each other by *direct* laboratory tests (to differentiate AA from AO, or BB from BO, surely, it is necessary to investigate the children or ancestors, or both, of the individual). These types or groups are given in Table 1, together with the corresponding designations in two other obsolescent systems of nomenclature which were applied before the genetics of blood grouping was understood. These earlier systems of naming are still unfortunately used to some extent in certain hospitals.

TABLE 1

DESIGNATION OF BLOOD GROUPS AND THEIR GENETIC FORMULAS

International, or Landsteiner Name (Phenotype)	*Group Jansky Name*	*Moss Name*	*Genetic Constitution (Genotype)*
O	I	IV	OO
A	II	II	AA or AO
B	III	III	BB or BO
AB	IV	I	AB

Now, knowing the way in which mature reproductive cells ("gametes") of each sex emerge with only one chromosome of a pair, and consequently only one gene of a pair, we can mathematically predict the way in which the blood groups will be inherited. When sperm and ovum merge it is readily understood that the resulting cell contains its set of *pairs* of chromosomes; each parent has contributed one member of each pair.

A man of group AB produces two types of sperm, one containing the factor A and one containing the factor B. These are produced on the average in equal numbers. A woman of group AB will produce two types of ovum, one containing A and one containing B. If such a man and woman mate, it will be a matter of even chances whether an A sperm fertilizes a B or an A ovum, and whether a B sperm fertilizes a B or an A ovum. So that three types of offspring could be produced, AB, AA, BB, BA. (The AB and BA offspring will be just alike, since each will have both substances in his blood). So the percentage of offspring, if we observe a statistically large enough number of such matings (or of children of one such mating), will be, and is, 25 per cent A, 25 per cent B, and 50 per cent AB. It is conventional in genetic literature to illustrate such a process of reasoning about the results of a mating by the checkerboard diagrams shown in fig. 2. (Either factor shown on the left may combine genetically with either of the two at the top of each diagram).

When we come to a mating involving an individual ("phenotype") of Group A or B we must remember that there are really two genotypes in each group; e. g. in A, one whose genetic constitution is AA (homozygous), and another whose constitution is AO (heterozygous). The first will produce only one kind of gamete (or sexual cell), all containing A, while the other will produce two types of gamete, 50 per cent containing A and 50 per cent not containing A.

Four of the 21 possible kinds of mating are shown in fig. 2. The third shows how a child's *group* may differ from that of either parent; the fourth shows why an O parent can not have an AB child or that an O child can not descend from an AB parent and *vice versa*. The reader will be readily able to work out the other 17 possible types of mating for himself,[1] and thus verify table 2.

[1]See them fully worked out for each of the 21 combinations in §165*b* of the "Supplement 1923-1933" to Wigmore's "Treatise on Evidence."

I	II	III	IV
Mating AA x AA	AA x AO	AO x BO	OO x AB
A A	A O	B O	A B
A AA AA	A AA AO	A AB AO	O AO BO
A AA AA	A AA AO	O BO OO	O AO BO
Progeny			
100% group A	100% A	25% O 25% A 25% B 25% AB	50% A 50% B

Figure 2

Diagrammatic examples of the hereditary transmission of the factors that determine certain blood groups. On the top of each diagram are designated the factors possessed (and transmissible) by one parent; on the left, those of the other; *which* parent does not matter, because this transmissibility has been shown to be independent of sex. The letters within the horizontal lines show the possible results in progeny.

The fundamental law is that any factor can not be present in the blood of a child unless it was present in the blood of at least one of its parents.

Diagrams of all the 21 possible types of mating are tabulated by Wigmore in § 165*b* of the 1923-1933 Supplement to his classical "Treatise on Evidence."

TABLE 2

BLOOD GROUPS OF OFFSPRING POSSIBLE OR IMPOSSIBLE FROM ANY MATING COMBINATION

	Alleged Father	*Known Mother*	*Possible Children from Their Mating*	*Children Not Possible from Their Mating. Decisive for Non-paternity*	*Impossible from This Mother in Any Mating*
1	O	O	O	A, B, (AB)	AB
2	O	A	O, A	B, AB	
3	O	B	O, B	A, AB	
4	O	AB	A, B	(O) AB	O
5	A	O	O, A	B, (AB)	AB
6	A	A	O, A	B, AB	
7	A	B	O, A, B, AB		
8	A	AB	A, B, AB	(O)	O
9	B	O	O, B	A, (AB)	AB
10	B	A	O, A, B, AB		
11	B	B	O, B	A, AB	
12	B	AB	B, A, AB	(O)	O
13	AB	O	A, B	O, (AB)	AB
14	AB	A	A, B, AB	O	
15	AB	B	A, B, AB	O	
16	AB	AB	A, B, AB	(O)	O

The letters designate the blood-types of the respective individuals. (See table 1.) Those in parentheses, in column 5, could not be children of the corresponding mothers (column 3) in any mating. (See Wigmore's complete tabulation of genotypic matings.) Therefore no such child could exist to raise a problem of proof, and these instances are omitted from table 3 which summarizes the net indications of non-paternity deducible from these blood groupings.

In the determinative application of blood grouping in bastardy proceedings, we have to consider the genetic compositions of the putative father and the known mother. It is also necessary to remember that at birth this grouping is complete, and final, in only about one-half of the infants. Actually, however, in this connection, the incomplete groupings seldom create uncertainty even in tests done soon after birth. The complete and permanent blood group characteristics, involving A, B, and O factors are attained before the age of two years, and, in a limited way, constitute an unchangeable means of identification; this can not be said of finger-prints.

The kinds of offspring from matings that involve only groups O and AB are relatively simple to predict since each of these groups (phenotypes) has but one genotypic formula (OO or AB), and the possible matings are only OO x OO, OO x AB, and AB x AB. But if either parent is an A or a B, there are two genetic formulas possible for each, which we are not able to distinguish, (without study of

ancestors and known progeny), so the problem of prognostication does become somewhat complicated.

Sample diagrams appear in figure 2 showing the kinds and proportions, of the children's blood groups engendered by homozygous x homozygous (AA x AA, example I), heterozygous x heterozygous (AO x BO, example III), and homozygous x heterozygous (AA x AO, example II) matings. By figuring out the kinds of offspring that can or can not result from all the 21 possible (genotypic) kinds of human mating we are enabled to construct table 2. Those offspring that can *not* result from a mating of the accused man and the woman in question indicate his non-paternity and are summarized in table 3.

TABLE 3

COMBINATIONS ALLOWING THE MAN TO ESTABLISH NON-PATERNITY OMITTING INSTANCES OF IMPOSSIBLE MOTHER-CHILD COMBINATIONS

(Condensed from Table 2)

Putative Father	*Known Mother*	*Known Child*
O	O	A, B
O	A	B, AB
O	B	A, AB
O	AB	AB
A	O	B
A	A	B, AB
B	O	A
B	B	A, AB
AB	O	O
AB	A	O
AB	B	O

Table 3 gives the combinations of putative father, identified mother, and identified child which prove that the man is innocent, and that some other must have fathered that particular child. The predictions based on this mechanism of blood group inheritance have been tested by the study of thousands of families, and are to be considered as certain as chemists' prediction of the behavior of a simple combination of known chemicals in the test tube.

III. CHANCES OF ESTABLISHING NON-PATERNITY

It will be apprehended without detailed explanation of calculations, that, knowing the percentile distribution of these four blood groups among the local population, we can calculate the *chances* that

if we determine the blood groups of putative father, known mother and infant, one of the combinations in table 3 will be found, and thus establish non-paternity. It is obvious that this will not always happen, for the real father may well be in the same group as the accused; almost half of our population belong in group O. If we know the group of the accused, we can calculate the chances that the groups of the mother and offspring will be such that non-paternity can be proven. These chances differ with each group. Such calculations were carried out by the present authors some years ago, and the results are reproduced in table 4. The method of calculating these probabilities is given in the appendix. Other authors have since derived very useful general formulas which enable us easily to compute these chances for any population of any distribution of blood groups whatever.

TABLE 4

PROBABILITIES OF PROVING NON-PATERNITY WHEN BLOOD GROUP OF WRONGFULLY ACCUSED MAN IS KNOWN (HOOKER AND BOYD)

Group	*Approximate Per Cent in the United States*	*Probabilities*
O	45	1/5*
A	42	1/17
B	10	1/7
AB	3	1/2
(If unknown		1/7)

*1/5 = 1 in 5 = 20 per cent.

It appears (*vide* "Unknown" in table 4) that, on the *average*, the chances are 6 to 1 against a man's being thus exonerated by recourse to these groups alone; he has but one chance in 7.

IV. THE NEW FACTORS, "M" AND "N" OF LANDSTEINER AND LEVINE

In 1927, Landsteiner and Levine reported on two definite but previously unrecognized factors in human blood, somewhat analogous to the older pair A and B, which they called "M" and "N". They showed that these factors are also inherited in an orderly manner. Since then many families have been examined, about 20,000 bloods tested for these new factors, and, due to these extensive investigations, the mode of inheritance is known with certainty, since in all these families the same rules were rigorously obeyed. The factors M

and N are inherited exactly like A and B, except that *an individual always has one or the other or both, never neither.* Not a single blood has been found having neither M nor N. So, the possible genetic formulas are MM, MN and NN, and, using the principles previously exemplified, the reader will be able to verify table 5 readily. *These* groups are established during fœtal life.

TABLE 5

MEDICOLEGAL APPLICATION OF THE AGGLUTINOGENS M AND N (WIENER)

Types of Parents	*Types of Children Possible*	*Types of Children Not Possible*
M+N+ x M+N+	M+N+, M+N—, M—N+	.....
M+N+ x M—N+	M+N+, M—N+	M+N—
M+N+ x M+N—	M+N+, M+N—	M—N+
M+N— x M—N+	M+N+	M+N—, M—N+
M+N— x M+N—	M+N—	M+N+, M—N+
M—N+ x M—N+	M—N+	M+N+, M+N—

The + and — signs mean respectively the presence or absence of the factor which they modify. Thus, M+N— signifies a person whose blood contains M but lacks N.

Wiener has calculated the chances of establishing non-paternity by means of these new factors. His results are given in table 6. Recourse to these new factors doubles the average chances which a wrongfully accused man would have if only the older A and B groups were used.

TABLE 6

CHANCES OF PROVING NON-PATERNITY BY USE OF THE M AND N GROUPS (WIENER)

Putative Father of Type	*Chances of Proving Non-Paternity*	
	Per Cent	*About*
M+N—	34.11	1/3
M—N+	41.09	2/5
M+N+	0	0
Unknown	18.64	1/5

TABLE 7

CHANCES OF ESTABLISHING NON-PATERNITY BY USE OF A, B, M, AND N FACTORS
(Based on Blood-Group Frequency Distribution in New York City (Wiener))

Putative Father of Type	*Probabilities*	
	Per Cent	*About*
O M+N—	50.71	1/2
O M—N+	56.00	3/5
O M+N+	25.18	1/4
A M+N—	40.37	2/5
A M—N+	46.67	1/2
A M+N+	9.05	1/11
B M+N—	43.59	2/5
B M—N+	49.56	1/2
B M+N+	14.38	1/7
AB M+N—	58.36	3/5
AB M—N+	62.77	3/5
AB M+N+	36.81	2/5
Unknown	33.07	1/3

Table 7 sets forth the probabilities of proving the non-paternity of a man who may belong to any one of the twelve groups that are identifiable by the presence or absence of A, B, M, or N.

V. COURT CASES

In New England there have been two cases, both in the New Haven Court of Common Pleas in which blood grouping evidence has been authoritatively introduced (see Wiener's article, in Reference List). In one of these cases the evidence was not determinative; in the other it was, and an account of this case (*Time*, Jan. 30, 1933) follows:

"Father's Blood

"Before a Connecticut justice of the peace one Edna Newton, 21, sulkily accused a Louis Rebuzzini, 28, of fathering her child. The justice believed her. Louis Rebuzzini hired a resourceful lawyer, who in turn hired Dr. Alexander S. Wiener, Brooklyn blood specialist. Dr. Wiener took samples of blood from mother, child and alleged father, examined the bloods this way and that according to the dicta of Nobel laureate Karl Landsteiner. Last week litigants, lawyers and blood man appeared before a county court in New Haven.

"While Edna Newton listened sulkily and Louis Rebuzzini sullenly, Dr. Wiener discoursed about blood types O, A, B and AB and certain substances called agglutinogens M and N, reasoned that if this-blood man fertilized that-blood woman, their offspring must have this-or-that blood and could not have such-or-such blood. All this meant that the Land-

steiner blood groups can show only that a man is *not* a child's father. But not in every case can blood matching prove innocence. For example, two putative fathers may belong to the same blood group. Nonetheless the blood groups suffice to clear one out of six falsely accused men.*

"In the New Haven case Louis Rebuzzini happened to be that one. Miss Newton withdrew her charges, convinced that Dr. Wiener's thesis was as valid as her own maternity.†"

VI. Technic of Testing

It is not proposed to describe here the methods of identifying blood groups. The O, A, B, and AB groups are easily identified, and the technic is well known, because this kind of test is an essential preliminary to the selection of donors for blood transfusions. The M and N groups are rather more difficult to identify, and comparatively few workers are thoroughly familiar with the special technic. The statement of Wiener—upheld by our own experience—can hardly be overemphasized: "It is therefore of the utmost importance that the (blood grouping) tests in medicolegal cases be performed by experts; *i.e.,* by individuals who have done a considerable amount of work with the agglutinogens M and N." In every test it is absolutely essential that the reagents employed be shown, at that time, to react *specifically* with the bloods of *known* (previously determined) type. Such technical controls are indispensable if the results of tests are to be trustworthy.

VII. Other Inherited Blood-Factors Which May Yet Be Useful

The inheritance of other human blood-characteristics has not been studied as thoroughly as that of A, B, M and N. But, as more work is done, the laws governing the inheritance of other factors will become known with sufficient certainty to allow their practical application. This may well happen within the near future and this probability should be borne in mind in appropriate medicolegal cases coming up at a time removed from the present writing by more than a few years. Certain additional blood grouping factors which are being investigated at present seem likely soon to acquire importance.

*If the agglutinogens M and N are also considered, the chances of proving non-paternity (or non-maternity) are one out of three.

†Lawyers of the American Medical Association have been unable to find any records of U. S. Appellate Courts passing on the validity of blood tests in paternity cases. But high Courts have accepted the tests in Germany, Austria, France, England, Denmark, Sweden, Switzerland, Italy. [Recently the N. Y. Supreme Court ordered blood tests in Beuschel v. Manowitz (N. Y. Times, Jan. 2, 1934; Time, Jan. 15, 1934) and the South Dakota Supreme Court reconsidered its prior rejection of blood grouping evidence. (Boston Herald, Feb. 9, 1934)].

Other heritable characteristics, such as eye-color, digital hair, direction of occipital hair whorl, *etc.*, should also be kept in mind. Many other such characteristics studied so far are of too infrequent occurrence to be forensically useful.

VIII. Other Medicolegal Applications of Blood Groups

Blood stains in suitable condition can not only be immunologically proved to be composed of *human* blood, but by blood grouping technic they can be allocated into the aforementioned twelve recognizable classes. It is obvious that, in much the same way as we are able sometimes to prove that a man is not the father of a child, we could in some instances prove that a stain was not his blood, and thus exonerate him of murder. In case a murderer's blood stain is available the chances of exonerating an innocent accused person, in this way, are 3/5 even if only the O, A, B, and AB groups are used. It has further been shown that certain blood types can be identified by testing the saliva, even when dried, as on cigaret butts or envelope flaps. Dried muscle may be similarly used and the problem of identifying the blood group of a person dead even for decades or centuries is probably not insoluble.

The blood groups can also be determined by examination of sperm and/or spermatic fluid. This invests seminal stains, resulting from successful or attempted *rape,* with forensic possibilities.

Non-maternity can be successfully established in a small per cent of cases. Similarly, under favorable conditions, among contesting heirs, false claimants might be excluded and the position of a true claimant strengthened.

Interchange of infants. The possibility of correctly allocating infants in cases of suspected interchange has been considered fully by Wiener. The chances are much higher, 7 in 10, than of proving non-paternity, and the method has been successfully applied.

IX. Alleged Exceptions to the Laws of Heredity of Blood-Groups

The voluminous literature on blood groups reports many thousands of tests carried out by hundreds of different workers. Some of these investigators certainly were not always working with the meticulous care that should be used in a medicolegal case, and it would not be surprising if a few technical errors were made. We may dismiss the errors of another kind, typified in Buchanan's reports, due to a misunderstanding of genetic principles. It is highly significant that in the literature since

1925, when Bernstein's mathematical analyses and hypothesis were published and became susceptible of independent test, there has been a striking reduction in reported exceptional findings. When data and methods must be submitted to the stringent tests demanded by competing hypotheses, and a knowledge of sources of error has been relatively popularized, we may expect—and actually do find—that a rigorous experimental technic has been much more carefully followed.

But, in addition to the minimizing of "exceptions" brought about by this influence, we find highly convincing objective validification of the hereditary mechanisms here discussed, in the studies of Wiener on the inheritance of M and N factors. A law implicit in their hereditary transmission is expressed thus: "The combinations M+N— parent with M—N+ child, and M—N+ parent with M+N— child are impossible." Now, if only *mother*-child combinations are examined, since thus, in the general run of families, the chance of illegitimacy is practically non-existent, it has been found that *in a series of 3487 cases, expertly tested, not a single exception occurred* (see Wiener's article, in the Reference List). In this series, each of the seven "exceptions" (0.2 per cent) to this law involved *father*-child combinations. Considering this result, in this large and statistically valid series examined under conditions of technical accuracy, could one ask for more cogently eloquent testimony that "exceptions" are due to illegitimacy?

In the case of groups involving factors A and B, the somewhat more complicated conditions of inheritance do not allow so simple a test of the invalidity of "exceptions"; but, since the same Mendelian principles of heredity apply with equal force, it is equally permissible to conclude that here, too, illegitimacy must be invoked in explanation of expertly determined "exceptions".

So far, not a single *completely proven* exception to Bernstein's explanation of the mechanism of blood group inheritance has been found. But, should there occur one exception in every thousand or several thousand cases, we need only compare this *almost perfect* reliability of the purely *objective* and verifiable evidence afforded by blood-grouping tests with the notorious unreliability of *subjective* and often unconfirmed evidence upon which, no doubt, many an innocent accused man has wrongfully been convicted.

X. Summary.

Attention is drawn to the medicolegal usefulness of blood grouping. Pertinent genetic principles are outlined and the statistically valid experimental evidences that support them are cited. By applying the strictly *objective* and verifiable evidence afforded by blood grouping a true solution can be reached in one-third of the medicolegal problems involving non-paternity. Except in the rarest of circumstances a *man can not be incriminated,* but he may this often

be exonerated. Other forensic applications of blood-grouping are mentioned.

Appendix

Computation of the Chances of Establishing Non-Paternity

Table 3 summarizes all the instances in which the designated child of the known mother could not be the offspring of the alleged father. The problem is to calculate the probability of the occurrence of these combinations.

First we must determine the probability that an individual taken at random will be in a given group. This is readily ascertained from the percentile representation of the various groups among the population with which we may be concerned. These figures for the United States are given in table 4. Thus the chances that a man (or woman) will be in group O are 45/100; but in group AB, only 3/100. These frequency distributions are independent of sex.

Next we must remember that the probability that a child will be in a given group depends upon the genotypic constitutions of its parents. For example, an O child may result from an AO x AO mating but not from AA x AO or AB x OO. This necessitates a calculation of the frequency of each genotype so that we may then compute, as we must, the group distribution of children that are born of women in each group.

Genotype frequencies are obtained as follows: There are three genotypic *factors*—A, B, and O. Let p = frequency of factor A; q of factor B and r of factor O; then $p + q + r = 1$. Random mating, which obviously occurs, gives all the possible combinations, represented by $(p + q + r)^2$, and their sum should equal unity. Expanding this algebraic expression we obtain

$$p^2 + 2pr + q^2 + 2qr + 2pq + r^2$$

and these symbols represent the frequencies of the 6 genotypes.

AA AO BB BO AB OO

We can now derive formulas that enable us to express genotype frequencies in *figures,* by substituting in these formulas the arithmetical or percentile distribution of the *groups* already determined by

testing a large enough sample of the population. The derivation follows:

$$r^2 = O \quad (1)$$
$$2pr + p^2 = A \quad (2)$$
$$2qr + q^2 = B \quad (3)$$

So,

$$r = \sqrt{O} \quad (4)$$

And, adding (1) and (2),

$$(r + p)^2 = O + A$$
$$r + p = \sqrt{O + A}$$
$$p = \sqrt{O + A} - \sqrt{O} \quad (5)$$

In the same way, adding (1) and (3),

$$q = \sqrt{O + B} - \sqrt{O} \quad (6)$$

Since there is but one genotype in group O and one in AB, it is obvious that their respective frequencies are equal to their percentile distribution as determined by direct test. Omitting a description of the simple process of substituting figures in the above formulas we now tabulate the frequency distribution of the genotypes, based on the aforementioned group frequencies in the United States.

TABLE 8

DISTRIBUTION OF THE SIX GENOTYPES

Genotypes	*Group*	*Frequency*	
OO	O		0.450 (r^2)
AA AO	A	0.42	0.068 (p^2) 0.352 (2pr)
BB BO	B	0.099+	0.005 (q^2) 0.094+ (2qr)
AB	AB		0.03 (2pq)

The small size of group AB makes it difficult to obtain a statistically valid figure, therefore the figure derived by applying the formula sometimes deviates slightly from that obtained by sampling the population. This has no significant influence upon the magnitude of the probabilities we are computing.

Having, now, the frequency distribution of the genotypes it is possible to compute the group frequencies of the progeny of all the mating combinations. It will be evident that women in group O mated with men in group A, genotype AO, (OO x AO) will bear,

on the average, 50 per cent of group A and 50 per cent of group O children. (*c.f.* diagrams in figure 2.) Since men of genotype AO constitute 35.2 per cent (table 8) of the male population, then 17.6 per cent of the children of women in group O will be in group A due to *this* kind of mating. The calculations for other mating combinations are similarly made and all are combined in table 9.

TABLE 9

FREQUENCIES OF THE VARIOUS GROUPS AMONG CHILDREN OF WOMEN (OR MEN) IN EACH OF THE FOUR GROUPS

Women	*Children*			
	O	A	B	AB
O	0.67	0.26	0.07	...
A	0.28	0.65	0.03	0.04
B	0.35	0.10	0.42	0.13
AB	...	0.47	0.37	0.16

Now we may proceed to the final computations. It is an axiom that the probability that two or more independent events will happen together is represented by the product of their individual probabilities. Selecting those instances permitting a man in group O to establish non-paternity (top section of table 3) and multiplying the corresponding individual frequencies (tables 4 and 9) we obtain the probabilities listed in table 10. Inasmuch as the probability that, of two or more independent events, one *or* another will happen, is the sum of the probabilities of the individual events, we add the fractions in the right hand column of table 10 and obtain 2057/10,000 = 21/100 = 1/5 which is the probability that a wrongfully accused man in group O will be able to establish his innocence by these tests.

The calculations are of the same type when the man is in group A, B, or AB.

If the putative father's group is not known we can compute only the probability that, whichever group he proves to be in, he will be able to establish non-paternity. The chances that he is in group O are 45/100 and if so the probability that he can prove his innocence is 2057/10,000. The product is 92,565/1,000,000. Dealing similarly with the other cases, and adding the results, we get 141,800/1,000,000 = 14/100 = 1/7.

The derivation of Wiener's general formulas, which are applicable directly to the group frequencies of any population, would have to be explained more abstractly and would be generally more difficult to understand.

These formulas are however very useful, give the same results that we have obtained, and enable us to avoid a lot of arduous arithmetic. They are given below. (The symbol P/o means the probability of thus establishing non-paternity for a man in group O).

$$\begin{aligned} P/o &= r^2(p+q) + 2pq(1+r) \\ P/_A &= q(p+r)^2 \\ P/_B &= p(q+r)^2 \\ P/_{AB} &= r^2 \end{aligned}$$

$$P/o,\ A,\ B,\ AB = p(q+r)^4 + q(p+r)^4 + pqr^2\,(p+q) + 2pqr^2$$

The formulas applicable to the M and N groups (see table 6) are as follows (m = frequency of *factor* M and n of *factor* N):

$$\begin{aligned} P(M+\ N-) &= n(1 - mn) \\ P(M-\ N+) &= m(1 - mn) \\ P(M+\ N+) &= O \\ P(M,\ N) &= mn(1 - mn) \end{aligned}$$

TABLE 10

PROBABILITIES OF ESTABLISHING NON-PATERNITY WHEN THE WRONGFULLY ACCUSED MAN IS IN GROUP O

Mother's Group	*Child's Group*	*Probability (Product)*
O 45/100	A 26/100	1170/10,000
O 45/100	B 7/100	315/10,000
A 42/100	B 3/100	126/10,000
A 42/100	AB 4/100	168/10,000
B 10/100	A 10/100	100/10,000
B 10/100	AB 13/100	130/10,000
AB 3/100	AB 16/100	48/10,000
		2057/10,000

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