CHAPTER 13

THE CRISIS IN EVOLUTION

THE CRISIS IN EVOLUTION

By the end of the 19th Century, the evidence that species could vary and change was overwhelming, so that one no longer needed the tedium of Darwin's exhaustive documentation. Likewise, although the firmest proof of the age of the earth (radioisotopic dating, measurement of time using the physical characteristics of light, and documentation of continental drift) was yet to come, numerous lines of evidence including astronomy, physics, several arguments from geology, geology, and biology all converged on the conclusion that the earth was at least millions rather than thousands of years old. Thus there was time to produce not only all the breeds of dogs but even to produce mammals, birds, frogs, insects, or grasses, trees, mosses, and ferns. One major impediment to accepting the idea that the earth could change was now resolved, and the idea of evolution began to achieve acceptance. However, this cognizance led to an unforeseen problem. As people began to accept the idea of evolution, they began to explore the mechanisms by which it could occur. And now there appeared a major theoretical problem: by common understanding of heredity, evolution could not work. We shall see shortly that common understanding was based on denial of the obvious, but nevertheless it was the province of contemporary scientific thinking and therefore an issue that ultimately caused Darwin to doubt his own hypothesis. The argument was as follows:

Throughout history and in many societies, the role of women in heredity has been treated with some disdain, even with completely self-contradictory arguments. "Bring forth men children only" (Macbeth to Lady Macbeth) simultaneously suggests that women have control over the choice and that they betray men by not producing boys, or that they decide the sex of the children, or that they provide fertile or infertile terrain for the development of male children contributed by the father, as was evidenced by many royal marriages being terminated (by one means or another) because the Queen did not produce a son. In the 19th Century, with the observation of sperm, the male-centric interpretation was that the man implanted a microscopic child into the woman (a homunculus, see Fig 13.1), and the woman was a sort of ambulatory flowerpot.

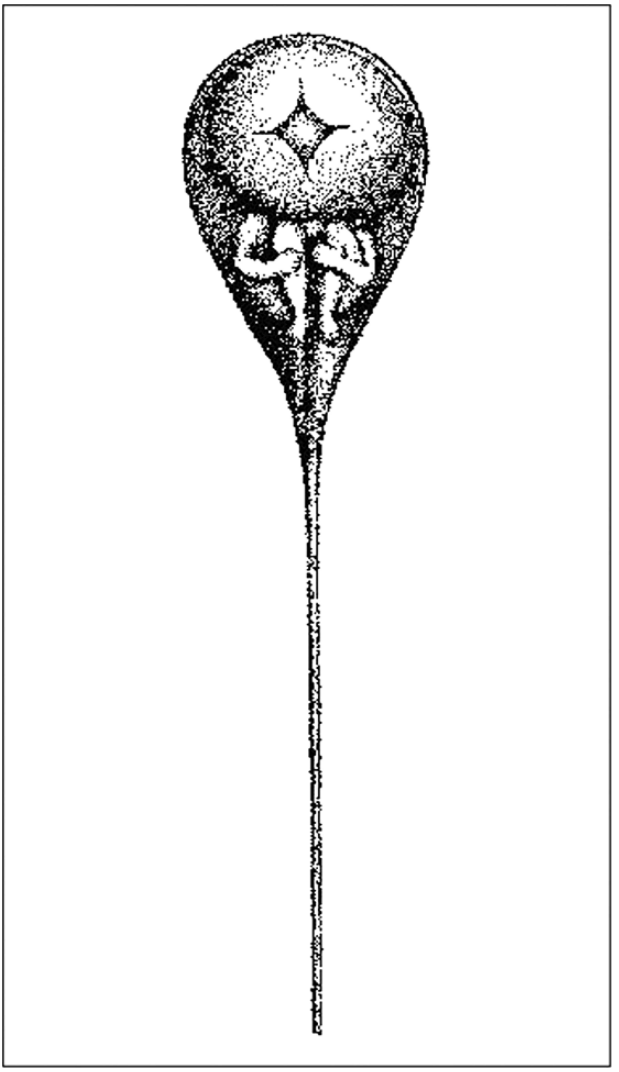

Figure 13.1. Homunculus. Image of a homunculus (Latin: tiny man) as early microscopists believed that they saw in sperm. Sperm had relatively recently been discovered, and even more recently determined to be natural constituents of semen rather than infectious parasites, and they had finally been associated with fertility. Furthermore, microscopes were able to resolve images barely smaller than sperm. In other words, they could distinguish the shape of sperm but not really determine any structures inside the sperm. This did not prevent microscopists from interpreting what they saw in light of the assumptions or prejudices of the time. (Because of the physics of light and the limitations of the human eye, today's light microscopes can more consistently see structures the size of sperm, but the theoretical limit of resolution is close to this size.) To determine structures within sperm or bacteria, some of which are approximately the same size, one needs to use an electron microscope or use any of several elaborate technologies or computer enhancing. Credits: From Nicolaas Hartsoeker's Essai de dioptrique (published in Paris, 1694, public domain (Wikipedia)

THE ORIGIN OF INHERITANCE

Even when thoughtful men conceded some contribution on the part of women to the child (since children could look like their mother), how this contribution got made was a matter of some speculation. The most reasonable idea seemed to be that essences of the parents were distilled into the gonads and were in some manner packaged into what would eventually be recognized as eggs and sperm. After all, children tended to look like parents. If the father had hairy fingers, how would that information get to the child other than by being carried through the blood to the testes and then into the sperm? Likewise, strong and athletic parents tended to have strong and athletic children. The parents were not born strong. Somehow the strength that they had acquired got collected and delivered to the children. Some of this mythology still exists in the rules and classifications in horse breeding, which distinguishes horses that have bred previously from those that have not.

There are two issues here. One is that characteristics are collected and distilled into the children, and the other is that the characteristics (like strength) can be modified throughout life, and the modified form delivered to the child. The modification argument carries a specific testable implication—i.e., it is a testable hypothesis—and it was extensively tested during the latter half of the 19th Century. The hypothesis was the inheritance of acquired characteristics, as represented by the following logic: A giraffe's long neck arose because generation upon generation of proto-giraffes reached ever higher for leaves on trees, their necks grew with constant stretching, and their children inherited the longer necks. Some rodents, such as guinea pigs or hamsters, have short or no tails. The experiment therefore is to cut off the tails of successive generations of mice. Eventually there should be nothing to distill to the babies (or, minimally, the tails have never been used and should atrophy) and babies will be born without tails. Lamarck had specifically proposed this argument, and the experiments were many times repeated, always with the same results: the babies always had full-length tails. Therefore, this element of the argument, that modified (acquired) characteristics could be inherited, went down in crashing defeat.

The other issue is the distillation of characteristics. If one argued the distillation of characteristics, then one would have to deal with the possibility that women could distill characteristics into eggs—and after all, both boys and girls could take after their mother's side of the family—but this created a very dangerous intellectual problem: dilution. In a nutshell, this is the problem: I have a brand new characteristic, one which in Darwin's terms makes me extremely fit. Let's say that I can photosynthesize my own food. My children ought to populate the earth. However, I am, to use 19th C terminology, a "sport," what we would today call a mutant. The characteristic appeared for the first time with me. That means, of course, that the woman I choose to marry does not have the characteristic. Since she contributes to the egg that she builds, let's concede that she contributes half of the characteristics. That means that my child gets only half of my ability to photosynthesize. Since my child will presumably choose a partner from outside of the family, rather than a brother or sister, my grandchildren will have only

one fourth of my ability to photosynthesize. In the course of a few generations, my wonderful ability will have been diluted to unmeasurable or ineffective levels. A "sport" or new mutation or new variant cannot be propagated in a population; it will inevitably be diluted into non-existence.

So we have a problem: Evolution is logical, it makes sense, there is evidence that it has occurred, but there is no way in which it can occur. Unless we can resolve this problem, we have to throw out the whole hypothesis. The hypothesis fails the L (Logic) part of the ELF rule.

SOLUTIONS TO THE PROBLEM

Toward the end of the 19th century, an observation gave a hint as to what might happen and, armed with this hint, several scientists set out to see if they could find a solution. The hint came from embryology. August Weissmann, doing a very careful study of how eggs and embryos developed, had come across some very peculiar colored bodies[5] (the literal translation of chromosome) that underwent an elaborate ballet every time cells divided. Not only did they undergo an elaborate ballet, the ballet in cell division that produced an egg or a sperm cell was very different from that when, for instance, a liver cell divided. He called the ordinary division of cells **mitosis**, and the division (actually a pair of divisions) to produce an egg or sperm cell **meiosis**. He was aided in coming to this conclusion by the fact that he had chosen for study some very small worms and insects, so that he could see the chromosomes without having to cut the animals up. In these animals, the different behavior of the chromosomes during meiosis as opposed to mitosis is spectacular (Fig 13.2).

What Weissmann saw was that, for one cell to make two cells, the chromosomes doubled before the cell divided, and then half of the total chromosome population went to each cell. Thus each daughter cell had as many chromosomes as the original, pre-division cell (Fig 13.2a). Very interestingly, in meiosis, the chromosomes doubled once, but the cell divided twice, so that each of the four daughter cells (eggs or sperm) ended up with half the number of chromosomes as the original cell. When the new individual was reconstituted with an egg and a sperm, the original number of chromosomes was restored (Fig 13.2b). So that's how it worked! Each individual consisted of half his mother's chromosomes and half his father's chromosomes. As an adult, this individual would produce eggs or sperm with half the number of chromosomes, and the fertilization would restore the number.

Weissmann had also recognized the cells that give rise to the sex cells (eggs and sperm) and begun the investigation that led to a second very important conclusion. In some animals, the cells that give rise to the sex cells, known as the germ cells, are recognizable in very young embryos, sometimes as soon as they are formed, and they can be followed throughout the development of the embryo. In insects, the

[5] The chromosomes are not colored, but they can be readily stained by the dyes that histologists were beginning to use.

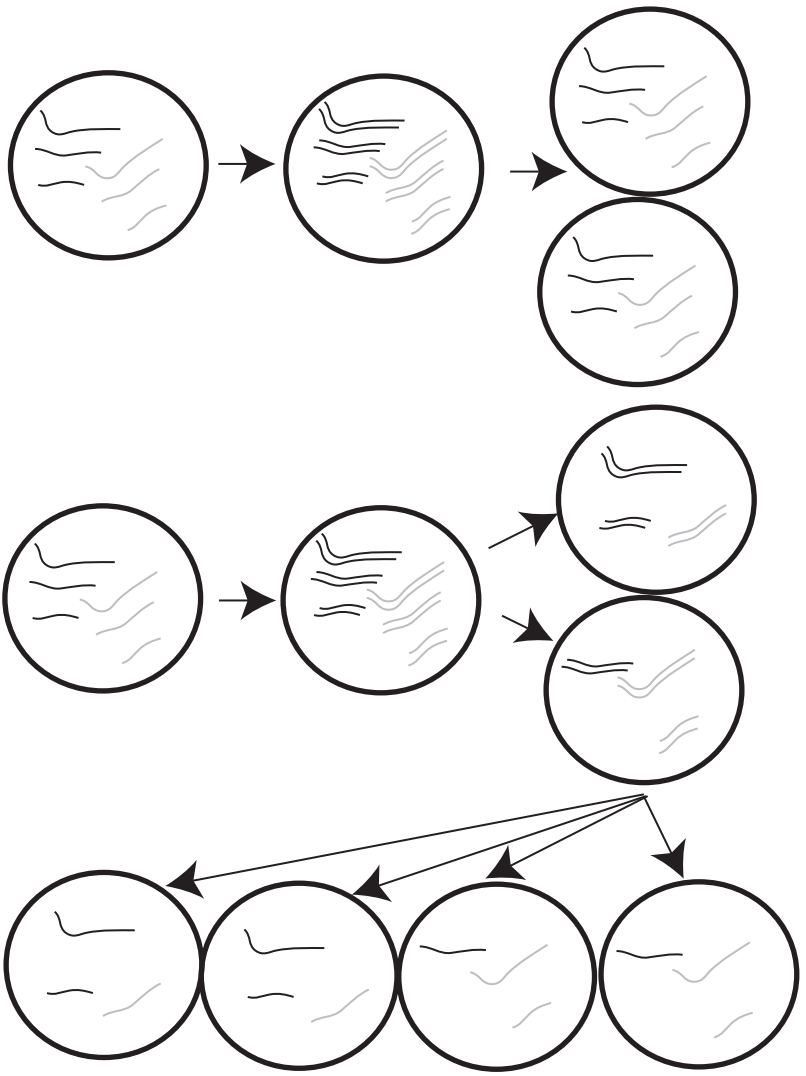

Figure 13.2. Mitosis and meiosis. The cells of most organisms contain two sets of chromosomes, one from the father (black) and one from the mother (gray). The number of chromosomes varies among organisms from one to hundreds. Humans have 23 pairs of chromosomes. Upper figure: The nucleus of this cell contains six chromosomes consisting of three pairs, distinguished by size. When the cell prepares to divide, each chromosome builds an equivalent partner, and the nuclear membrane dissolves. At this time the chromosome is described as consisting of two chromatids (the partners). Each chromosome, with the chromatids still attached, lines up in the center of the cell, and one chromatid of each chromosome is towed into each of the two developing daughter cells. The nuclear membranes reform, and there are now two cells identical to the original mother cell.

In meiosis (lower panel), which occurs in germ cells, The chromosomes double as before, but in the first division one entire chromosome consisting of the two chromatids, from either the mother or the father, moves into each daughter cell. The choice is random, so that each cell will end up with a random mix

germ cells even at one point reside outside of the embryonic body proper (Fig 13.3) Thus in addition to the lack of evidence supporting Lamarck's hypothesis, one could now argue that the germ cells were physically separate from the body, the characteristics of each individual were carried in the chromosomes that resided in the germ cells, and that chromosomes would not migrate from the cells of the body (or soma, from the Greek word meaning, not surprisingly, "body") to the germ cells. Thus there was further evidence against the hypothesis of inheritance of acquired characteristics.

We have progressed to the point today that germ cells can be transplanted from one animal to another, and the results are consistent with the interpretation that they do not change. For instance, if one identifies an easily recognizable characteristic such as body color, and transplants the germ cells from an ebony-bodied fruit fly to an egg from a yellow-bodied fruit fly, the egg will develop into a normal, fertile yellow-bodied fly but will bear young that are ebony-bodied. The inherited characteristics are determined by the characteristics of the germ cells (Fig 13.4).

In terms of the primary problem, that of dilution of mutations, the recognition of chromosomes suggested a possible solution. Chromosomes were not diluted from generation to generation. They duplicated, were divided equally, and recombined to form a new individual. Perhaps it was possible that inherited characteristics could also be preserved intact? But chromosomes could not be characteristics. Humans have only 46 chromosomes (23 pairs) but obviously far more than 23 or 46 different characteristics. Some animals and plants have only 4 or 5 pairs of chromosomes, and there are even some with a single chromosome pair. What was the connection?

THE SEARCH FOR THE RESOLUTION OF THE PROBLEM

Thus in 1900 there was considerable scientific ferment, with the question of how one could resolve the problem of dilution, evidence that germ cells were not changed by their residence within the body, and some suggestion of a means of not diluting characteristics. Thus it was not a lucky or bizarre accident, but a product of the way science works, that three laboratories simultaneously rediscovered Mendel's original paper, which carried the potential solution to the dilution problem. Mendel's paper was not totally obscure. It was published in a reputable journal, but it was mathematical, theoretical, and—to be frank—probably boring to the evolutionary theorists. What Mendel had done was to see if the laws of chance, then being worked out by mathematicians to understand how gambling worked (and for the practical reason of helping casinos, which were then very popular, calculate odds that would ensure a

Figure 13.2. of these chromosomes. The cells then divide again, but in this division the chromatids separate as in mitosis. The result is one duplication plus two divisions, so each of the four resulting cells contains half the DNA of the starting cell, and has only one copy-randomly from mother or father-of each chromosome. These cells are the future eggs and sperm. When a sperm fuses with an egg, the original number of chromosomes is restored

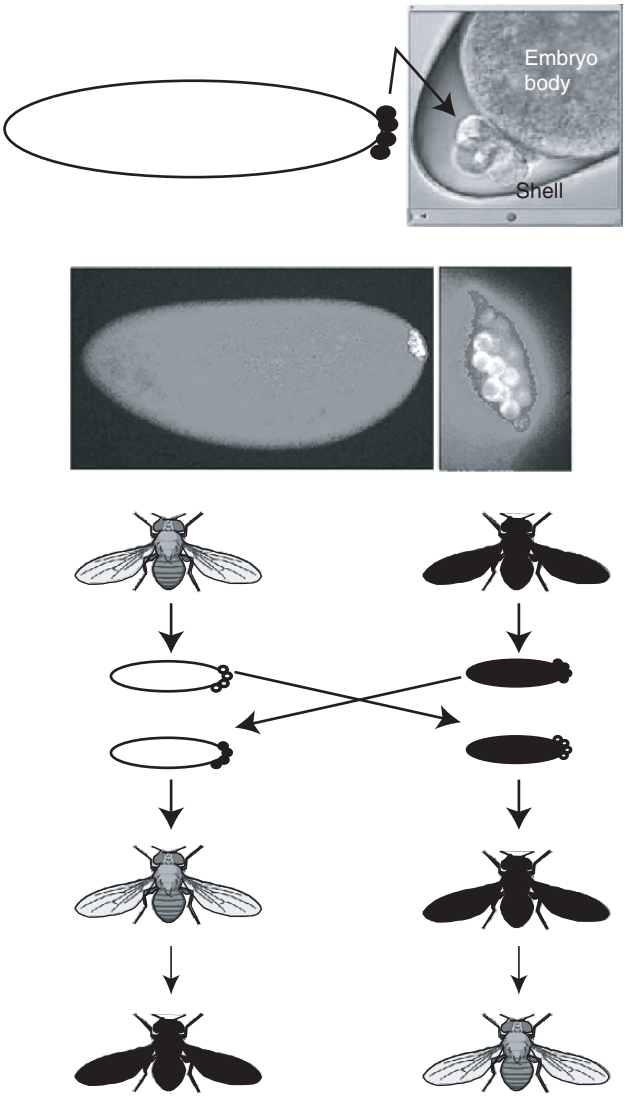

Figure 13.3. Insect pole cells. In most insects, before the embryo has taken shape a small group of cells briefly accumulates at the posterior end of the embryo (left figure, arrow). In the 19th C, André Haget, a French biologist, destroyed these cells with a hot needle and was surprised to find that, although the larvae were normal, the adults were as normal as they could be except that they were completely sterile. Subsequent studies traced these cells ultimately to the gonads (ovaries or testes), and similar, though far more obscure, cells were found in the eggs of vertebrates. Right figure: Pole cells in the embryo of a small wasp. Middle: Pole cells at the posterior end of in a fruit fly (*Drosophila*) embryo. The pole cells have been stained so that they fluoresce green. Lower: When pole cells are transplanted between a normal-colored fruit fly and a black fruit fly, the eggs turn into flies of their host color but produce young of the transplant color http://www.snv.jussieu.fr/bmedia/CoursPCEMDEUG/DocDrosimage/Drosophila%20pole%20cells.jpg. Credits: http://www.snv.jussieu.fr/bmedia/CoursPCEMDEUG/DocDrosimage/Drosophila%20pole%20cells.jpg

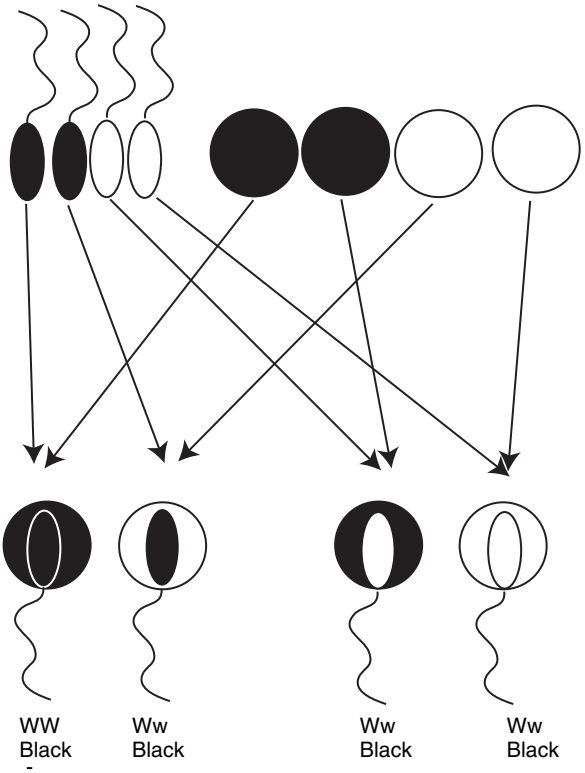

Figure 13.4. The genetics of color. For any trait such as color illustrated here, each sperm and each egg will be descended from the four cells of a meiotic division, and will have one chromosome for the color trait, either from the mother or the father. The illustration here assumes that the mother and the father both have one black and one white trait. If they are pure-breeding, all the eggs or sperm will be the same. Each of the products of meiosis is illustrated, since the chance of getting either one is random. We also assume that if the resulting child carries any copy of the black trait, its color will be black, since for many genes one version is the absence of another version. Here, the black trait is the ability to make black pigment, and the white trait is the absence of that ability. Depending on which egg combines with which sperm, we will on average get three black animals for every white animal. Two of these three will, like their parents, be able to produce white grandchildren. One of the black animals, and the white animal, will breed true, since it does not contain the other trait. We conventionally describe this situation by designating the black trait as dominant and the white trait as recessive, and geneticists usually symbolize these relationships by giving the characteristic the letter designation of the recessive gene, symbolizing the recessive variant by lower-case type and the dominant variant by upper-case type. Thus the phenotype (how the animal appears) is black or white, as written out. The genotype (what its genetic composition is) is WW (pure-breeding or homozygous black), Ww (black but not pure-breeding or heterozygous), or ww (white and homozygous or pure-breeding).
Note: human racial coloration is far more complex than this and consists of several genes. Also, if for the heterozygous forms the animal containing a single copy of the gene was able to make far less pigment than the homozygous form, the heterozygote might be distinguishable as gray, not black. Flowers may be pink rather than deep red because of such a situation

profit), would apply to inheritance of characteristics as well. In other words, he wanted to see if the chance of getting blue eyes followed the same mathematical laws as the chance of getting two heads in a coin flip or rolling two ones with dice. In 1900, three groups finally realized that this dry mathematical exercise provided the key to the dilution problem. Characteristics could be passed from generation to generation without dilution. The key lay in the way that Mendel did his experiment.

What Mendel did was very simple: Instead of asking, in effect, "Does this girl look more like her mother or her father?" he asked, "Is the color of her eyes that of her mother or her father? Is the color of her hair that of her mother or her father?" In other words, he subdivided general impressions into highly localized or specific characteristics, and only then did he see very clear-cut patterns. Specifically, he saw that some characteristics could hide other characteristics, but that the hidden characteristics could reappear in later generations, unchanged, undiluted, and unaffected by passage in an individual with different characteristics.

All this sounds very abstract, but it can be described in easily comprehensible terms, and terms that scientists of the time might have recognized had they understood that human inheritance was like that of animal and plant inheritance. Throughout the world, but especially in northwestern, northern, and eastern Europe, most scientists had encountered the situation in which a red-headed child was born to a couple with dark hair but in whose families redheads had been seen. It was simply the situation of, "Little Mary has Uncle Ed's red hair!" This was the essence of what Mendel had described. Characteristics (red hair) could be passed hidden from one generation to another, and reappear uncorrupted in a new generation. It should have been obvious to anyone who thought about it, it resolved the conundrum of the dilution problem, and it took 35 years to rediscover the experiment that explained it.

MENDEL SAVES EVOLUTIONARY THEORY

The rediscovery of Mendel resolved that last huge hurdle to the intellectual acceptance of evolution and led to general acceptance in the scientific community of the theory of evolution. This general acceptance and popularization of the theory led to a resurgence of theological and religious challenges that will be addressed later. At this stage it is important to understand what Mendel's experiments and results were, and how they were interpreted. Like all scientific information, what Mendel saw and interpreted has been subjected to some adjustment, as some variations and finer details have come to light, but the essence of his results are as follows. You can read his original paper on the internet at http://www.mendelweb.org/.

Mendel was an Austrian monk who raised peas in his garden. He wanted to see how pea characteristics were inherited and, as noted above, he subdivided the characteristics that he chose to observe. Pea plants can differ in many characteristics: the plants can be tall or short; the peas can be yellow or green; they can be wrinkled or round; the flowers can be purple or white; etc. Rather than treat inheritance as one complex muddle, he asked very simple questions: if he crossed peas with purple flowers with peas with white flowers, would the flowers of the resultant pea plants (the children) be purple,

light purple, or white? If he crossed tall peas with short peas, would the children be tall, short, or intermediate? If he crossed plants bearing yellow peas with plants bearing green peas, would the peas be yellow, green, or yellow-green? Would the offspring of plants bearing wrinkled peas and plants bearing round peas be wrinkled, round, or in between? What he found was startlingly simple and unconfusing.

To make this discussion clearer, it will help to use the terminology that geneticists use. The crosses originate between two pure-breeding lines, that is, peas that always produce purple flowers are crossed with peas that always produce white flowers. The peas in this cross are the parental or P generation. The seeds that are produced in this cross become the first filial or F_1 generation. (Students familiar with any Romance language will recognize the fil-root as indicating son or daughter.) These plants are then crossed with each other (there are no laws or customs forbidding brother-sister marriages in plant breeding) and the seeds produced from these crosses are the second filial or F_2 generation. In symbolic form:

$$P_a \times P_b \longrightarrow F_1 \otimes \longrightarrow F_2$$

What Mendel saw was the following: ALL of the F_1 generation looked like one parent, not the other. In other words, in the flower color cross, all of the F_1 plants produced purple flowers. There were no light purple flowers or white flowers. The white characteristic had disappeared. Similarly, in the tall/short cross, all the progeny were tall; in the yellow/green peas cross, they all had yellow peas; and in the wrinkled/round cross, all the peas were round. There were no intermediates, and one characteristic had disappeared.

He then inbred the F_1 generation to get an F_2 generation. In this second generation, the lost characteristics reappeared. There were no intermediates, but there were white flowers, short plants, green peas, and wrinkled peas. Not only did these lost characteristics reappear, but they reappeared in a specific pattern. The lost characteristics reappeared as approximately one fourth of the plants. There were three plants with purple flowers for every plant with white flowers, and so forth. The actual data from Mendel's experiment are shown in Table 13.2.

To Mendel, this was a distribution indicating that the characteristics combined as a matter of chance, since the mathematics was the same as that for flipping coins: He invented a specific description: the traits that appeared in the F_1 generation were "dominating" (today we say "dominant") and those that disappeared were "recessive". Mendel recognized that what he saw was chance recombination. For instance, if one flips two coins, one has an equal chance of getting each of these four combinations: two heads; heads, then tails; tails, then heads; and two tails. If one ignores the tails and counts only the times that one gets at least one head, then one will get at least one heads in three out of four double tosses. Mendel explained that, if the purple trait could hide the white trait, as was seen in the F_1 generation, then the three purple to one white ratio was identical to the "at least one heads" ratio. All he had to hypothesize was that each parental plant contributed at least one "coin" or color characteristic. The purebreeding purple flowers would produce only purple characteristics, and the purebreeding white flowers only white

characteristics. Each plant would have two of each characteristic, since the F_1 had to have two. The cross would be as follows:

Purple, purple x white, white ⟶ purple, white, which would be purple since purple could hide white.

Here we need a little terminology. The F_1 plant has a **phenotype** (appearance) of purple, since it is purple. However, its **genotype** is hybrid; it has a purple character from one parent and a white character from the other. Thus it differs from the purple parent, which has only purple characteristics, and from the white parent, which has only white characteristics. Since the plant as it grows bears two copies of a color trait, it is **diploid**, and the unfertilized eggs (seeds) and sperm (pollen), which each have only one copy, are **haploid**. The pure-breeding strains, which have the genotypes of purple, purple or white, white, are **homozygous** (from the Greek, "like eggs") and the F_1 plant, which has the genotype purple, white, is **heterozygous** ("different eggs").

If two of these F_1 hybrid purple plants are crossed, each will contribute both purple and white characteristics to the children. Each pollen grain or each seed will contain only one copy of the color characteristic, either purple or white, and the double, diploid, form will reappear when one egg combines with one pollen grain. The cross can produce four possible outcomes, as indicated by the Italics (Table 13.1):

Some of Mendel's actual data were as is illustrated in Table 13.2:

Or, on average, there will be three purple F_2 to one white F_2. The conclusion, therefore, was that characteristics were discrete and not blends or dilutions, that

Table 13.1. The results of genetic crosses

F_1 Genotypes (all Purple, white)	F_1 Phenotypes (each plant produces purple flowers)	F_2 Genotype	F_1 Phenotype
Purple, white × *purple*, white	Purple, purple	purple, purple	Purple
Purple, white × purple, *white*	Purple	purple, white	Purple
Purple, *white* × *purple*, white	Purple	white, purple	Purple
Purple, *white* × purple, *white*	White	white, white	White

Table 13.2. Mendel's data

Plant type	Total Yellow	Total Green	Total Round	Total Wrinkled
315 round, yellow	315		315	
101 wrinkled, yellow	101			101
108 round, green		108	108	
32 wrinkled, green		32		32
TOTALS	416	140	423	133
RATIOS	2.97 to 1		3.18 to 1	

they could be hidden, that they could reappear intact in a future generation, and that they were distributed randomly among children.

INTERPRETING MENDEL

It helps to have a little sense of how this works. In many situations, the recessive form is the absence of the dominant form. For instance, for the purple and white flowers, the plants that make white flowers cannot make the purple pigment. Usually, this happens because the plant carrying the recessive trait has lost the mechanism (an enzyme[6]) to make the pigment. When it is crossed with a plant that can make the pigment, the plant that results now has the enzyme, the pigment is made, and the flowers are purple. It is very much the same as the following: if both you and your spouse have keys to the car, even if you lose yours, you will still be able to drive the car as long as one key remains.

We will call the characteristic a **gene**, and we will use the term in the sense that "he carries a gene for red hair". The gene that can mask another gene is a **dominant gene**, and one that can be masked is a **recessive gene**. For instance, carrot-red hair is typically recessive to truly black hair. If one parent comes from a line of only black-haired people and the other from a line of only redheads, the child (F_1) is likely to be black-haired (heterozygous, carrying both the gene for black hair and the gene for red hair) but could produce red-haired children (F_2) if he or she married someone who similarly carried a gene for red hair.

Although the situation is more complex and we will need some more explanation of the structure of genes, for the moment we will consider that a gene is the information to make something, such as a pigment. The gene itself is DNA (defined on page 193) and carries the information how to make an **enzyme**, which is a protein that can carry out a specific reaction, for instance converting a red pigment to a black one. From this you can see how most dominant and recessive genes work.

Hair pigments are made from chemicals (molecules, which are the individual particles of chemicals) of different colors, in the following sequence (Fig 13.5):

1. A colorless pigment is converted into a yellowish pigment.
2. The yellowish pigment is converted into an orange pigment.
3. The orange pigment is converted into a red pigment.
4. The red pigment is converted into a brown pigment.
5. The brown pigment is converted into a black pigment.

Each step here is accomplished by a specific enzyme (page 184). A red-haired person has the enzymes to complete steps 1, 2, and 3, but lacks the enzyme to complete step 4, and the synthesis stops at that point. Stopping after step 1 would yield a blond.

A black-haired person can complete all five steps. Thus in the F_1 heterozygote, the child of the black-haired parent and the red-haired parent, the gene for the enzyme

[6] See further discussion in Chapter 15, page 221.

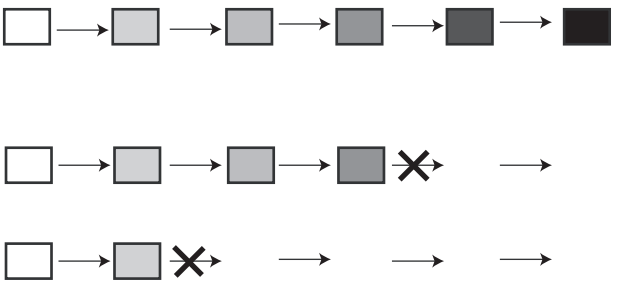

Figure 13.5. Pigment formation. Upper row: The synthesis of a pigment is a several-step process, with each step controlled by a specific enzyme. Thus, in this sequence, an uncolored precursor material is converted successively into yellow, orange, red, brown, and finally black materials. Middle row: The enzyme converting the red pigment to brown is lost, or mutated. Synthesis of pigment stops at this point, and the resulting animal is red rather than black. Lower row: The enzyme converting the yellow pigment to orange is mutated, and the animal consequently has a yellow coat color

for step 4 is missing from the genes of the red-haired parent but is contributed by the genes of the black-haired parent (Fig 13.6).

Thus this child will be able to complete the synthesis of the black pigment and will be black-haired. Should this black-haired child produce an egg or sperm carrying the defective enzyme 4, and this egg or sperm combine with a sperm or egg from a partner likewise carrying the defective enzyme 4, the resulting child would be red-haired.

Most genes operate in more-or-less this manner, and Mendel's laws of inheritance can be demonstrated in all animals and plants. Mendel's interpretation provided the explanation of why new characteristics (mutations, "sports") are not lost in subsequent generations. They are not diluted but are passed intact, even though their effect may not be seen.

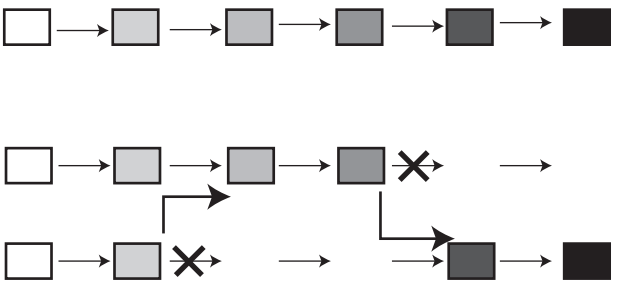

Figure 13.6. Complementation: Lower two rows: The heterozygous child of a red-haired parent and a yellow-haired parent can be black haired, because the defective yellow-to-orange enzyme produced by the one chromosome can be replaced by a good enzyme from the other chromosome, and the defective red-to-brown enzyme of that chromosome can be replaced by the good enzyme from the first chromosome. Thus pigment formation can be completed

Genes are physically very tiny, and we now know that they are lined up on the chromosomes. For instance, there are 20–25,000 human genes, and there are 23 chromosomes, making an average of 1,000 genes per chromosome. Each time a cell divides, whether in mitosis or meiosis, the duplication and movement of the chromosomes carries the genes appropriately into the new cells.

Thus 1900 was somewhat a turning point for the acceptance of the theory of evolution. The evidence for the relationships among animals and plants was abundant; examples of selection could be found almost anywhere one looked; it was now evident that the earth was old enough to have supported the evolution of all the species known; and now it was apparent that characteristics could survive and be passed to future generations. But rather than continue with the history of the social acceptance of evolution, let us first examine, in the following chapters, the evidence for it and the mechanisms by which it works.

REFERENCES

http://www.mendelweb.org/ (Mendel's original paper, from an international resource for the web)

STUDY QUESTIONS

1. Consider the state of knowledge both at the end of the 19th C and today. What are the weaknesses of the theory of evolution, that is, that populations overbreed, there is competition among individuals and selection of the fittest, and that this process gradually changes species? The theory also includes the assumption that such processes could have generated all the life forms that exist or have existed on earth.
2. Some inherited characteristics are not inherited according to the simple rules that Mendel saw. For instance, when one crosses red and white flowers, one might get pink flowers. Can you formulate a hypothesis as to how this might work?
3. Other characteristics also do not form simple Mendelian ratios. For instance, people do not divide into tall, average, and short. Within a range normally of about 5 feet to 6 ½ feet, we find adult humans of all possible sizes. Can you formulate a hypothesis as to how this might work?
4. As noted in this chapter, there are thousands of genes on each chromosome, and the chromosomes move as units into daughter cells. If two genes, say for eye color and for hair color, are on the same chromosome, is it likely that the trait for eye color will separate randomly from that for hair color? Explain.
5. What question did the discovery of chromosomes resolve? What question did the discovery of germ cells resolve?
6. Can you speculate how scientists determined that genes were arranged in a linear manner on the chromosomes? What evidence would they have needed? Do not look at this question as an expectation of your knowledge of detail. Consider how you would go about determining whether or not there was an order to a string of beads, based on how frequently you encountered specific groupings and breaks.