Historian's demythologizing acid

Fabulous Science. Fact and Fiction in the history of scientific discovery.
by John Waller.
Oxford University Press, 2002. 308 pp.

reviewed *by* Gert Korthof 24 Aug 2003 (updated 14 Sep 2005)

Mendel never grasped the basic tenets of Mendelian genetics (9), Darwin was a Lamarckist throughout his life and Pasteur suppressed unwelcome data. - This is the disturbing message of John Waller's Fabulous Science. We know that scientists rewrite the history of their discipline and create myths around the founding fathers of their disciplines. But Waller's demythologizing acid so aggressively corrodes the myths of our scientific heroes and revolutions, that one cannot help wondering whether any heroes or revolutions survive his treatment at all.

Pasteur: right for wrong reasons

The chapter about Pasteur is illuminating and relevant for the current Evolution/Creation controversy. It appears that Pasteur was a creationist (he believed the Genesis story) and firmly opposed the possibility of spontaneous generation of life. Darwin's work appeared around that time. Pasteur and 'his friends' were opposed to evolution. According to Waller, Pasteur and his friends played an unfair game and did not give their opponents a fair hearing. He suppressed unwelcome data. Today we would label that 'unprofessional conduct'. Ultimately Pasteur was right, but for the wrong reasons. Waller is remarkably mild in his judgement of Pasteur: "his sins were of a comparatively modest nature."

Mendel did not understand Mendelian Genetics!

"Mendel never grasped the basic tenets of Mendelian genetics" is Waller's sensational claim. This seems absurd and a great insult for the father of genetics. The most important evidence for this claim is the fact that Mendel described the results of his crossings as A + 2Aa + a instead of AA + 2Aa + aa, which now is the standard textbook formula. The rediscoverers of Mendel and later textbook authors as well as historians of science ignored Mendel's single A. Why did Mendel wrote the single A for homozygotes? It seems that Mendel thought that homozygotes and hybrids (heterozygotes) are fundamentally different. Mendel reasoned that hybrids produce two different kinds of seeds, therefore must have two different hereditary factors for colour, whereas homozygotes have only one kind of factor for colour. That's why he wrote A for homozygotes. Indeed Waller has a point here. We cannot ignore this fact. Did he really fail to infer that homozygotes not only have two identical kinds of factors but also no more and no less than exactly two factors in each body cell? I examined the online version of Mendel's publication (English translation). This is what Mendel wrote:

> The result of the fertilisation may be made clear by putting
> the signs for the conjoined egg and pollen cells in the form of fractions, those for the pollen cells above and those for

the egg cells below the line. We then have

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  A       A       a       a
----- + ----- + ----- + -----
  A       a       A       a
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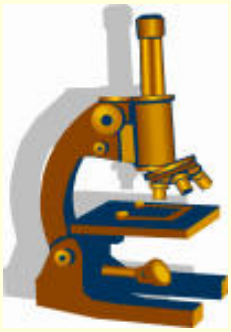
So Mendel knew that both egg and pollen had an A, so the combination of both in a zygote must be AA. Mendel further wrote:

"We may write then A/A + A/a + a/A + a/a = A + 2 Aa + a."

How strange! So the single A in Mendel's notation was an abbreviation! Waller ignored this. Nonetheless a confusing abbrevation. Ernst Mayr suggested that Mendel believed in a fusion of identical factors (4). That could explain Mendel's abbreviation. Identical factors A and A blend (!) and non-identical factors A and a do not blend. Surprisingly, Mendel's theory was a mix of **blending** and **non-blending** inheritance! Today we understand that the concepts diploid and haploid, so familiar to us, were not known in Mendel's time. Without the knowledge of these universal concepts, Mendel had difficulties in inferring that all hereditary factors come in pairs, although that knowledge is not enough. Despite that Mendel understood that hereditary characters present in egg and pollen are brought together in the zygote, he subsequently simplified his expression for homozygotes.

microscopes and chromosomes



Waller claims "it would be most unreasonable to suppose that he [Mendel] could have done so. The idea of allelic pairs only began to make real sense around 1900 - when scientists had good enough microscopes to detect the existence of chromosomes". The good thing here is that Waller connects Mendelism and chromosomes (16), but there are two reasons why I think Waller's claim is wrong. The first is the timing and the ambiguous nature of the cytological evidence. The second reason is the logic of the Mendelian ratios.
Waller is imprecise in the timing. Crucially, at the time of the rediscovery, 1900, it was not accepted that chromosomes exist in pairs, that they pair and then separate in the formation of germ cells. It was not until 1903, three years after the rediscovery, that W. S. Sutton gave the first modern interpretation of the relationship between genes and chromosomes (7). This is further confirmed by Portugal and Cohen: "Within a few years **after** the verification of Mendel's work, the relationship between the chromosome (but not DNA) and Mendelian genetics was established" (8). But even this knowledge is not enough to explain the Mendelian ratios. Historian Jan Sapp points out (discussing meiosis) that "a crucial idea was lacking: cytologists had not yet generally agreed on chromosomal individuality - the notion that different chromosomes had different properties. In 1883 Wilhelm Roux postulated that each chromosome carried different hereditary determinants. But the experimental evidence was not reported until 1902 [**after** the rediscovery!], when Theodor Boveri announced that each of the 36 chromosomes of the sea urchin were necessary for normal development." (15).

Despite Sutton, there had been much reluctance among geneticists to accept the chromosomal theory of heredity. William Bateson (1861-1926), the father of the word 'genetics', the founder of the Journal of Genetics and one of those who reproduced Mendel's results, never accepted the chromosomal account of inheritance! Therefore, the connection between chromosomes and Mendelian genes, is certainly not self-evident (19,20).

'Seeing Genes'
Waller attributes impossible knowledge to the early geneticists: "new staining techniques had even made it possible for Morgan's team **to see** the areas on individual chromosomes where particular **traits** were coded for." It is correct to say that differently stained areas on chromosomes can be seen. Strictly speaking, **to see** 'hereditary traits' on chromosomes is impossible. Morgan never could see 'genes', they were still hypothetical. He could see stained chromosome bands. Only Watson & Crick were in a position to claim that chromosomes contain genes made of DNA. Only later in situ hybridisation produced indirect visual evidence that genes were located on chromosomes. But still the expression 'to see a gene' should not to be taken literally.

Furthermore, pre-1900 cytological knowledge about mitosis and meiosis would not have helped the rediscoverers very much (17). The relation between Mendelian factors and chromosomes is not so simple. How could a varying number of stainable threadlike particles of different lengths and forms, which were called 'chromo-somes' (stained bodies), be identified as the carriers of heredity? We should certainly not make the mistake to associate chromosomes with DNA, because this powerful association only developed decades **after** the rediscovery of Mendel. Furthermore, why should animal chromosomes behave in the same way as plant chromosomes? Why could it not be a coincidence that chromosomes come in pairs and Mendelian factors come in pairs too? Illustrative of the incomplete knowledge of the time is that August Weismann [before 1900] envisaged that **each** of the many chromosomes present in the cell nucleus carries **all** of the hereditary units necessary for producing the entire individual. In Pisum sativum, whose nuclei contain 14 chromosomes, this theory was clearly incompatible with Mendel's (then still unknown) inference that the pea plant is endowed with **two**, rather than fourteen, copies of each of its hereditary units (11). For humans it would mean that there are 46 copies of each gene. Weismann's theory is opposed to the whole idea of diploidy and the idea that each gene is present in pairs. Therefore, it is clearly not enough to know that sperm and egg contribute the same number of chromosomes, that chromosomes come in pairs, and that those pairs pair and segregate during meiosis. One needs to know that each chromosome pair is unique and contains only one pair of a specific gene. It is crucial to know how many copies genes have and how they are distributed over chromosomes. One cannot see that through a microscope.

the logic of the ratios

The second reason why I disagree with Waller's claim that it would be most unreasonable to suppose that Mendel could have inferred the idea of allelic pairs, is the logic of the Mendelian ratios. The 3:1 ratio logically requires that the hereditary factors exists in pairs! (at least for heterozygotes). The assumptions are:

1. hybrid parents produce 2 different gametes with only one factor per gamete
2. the 2 types of gametes are produced in equal proportions
3. this gives 4 possible equally likely combinations of the gametes

The conclusion from these premises is that 1 out of 4 has the recessive phenotype and 3 out of 4 have the dominant phenotype. If these assumptions are violated, for example the 2 different gametes are produced in unequal proportions, or a gamete contains 2 factors instead of one, then by logic alone, a different ratio results. For example, a tetraploid (4N) produces very different ratios: 35 : 1 or 21 : 1 (depending on the location of the gene on the chromosome). So, in a tetraploid the recessive phenotype has always a lower frequency than the 3:1 ratio of diploid (2N) parents. Certainly 'hundreds or thousands of hereditary elements' do not produce a 3:1 ratio. In that case a plant with a recessive phenotype would be extremely rare. So although Mendel did not have independent evidence for each assumption, taken together the assumptions perfectly explain the 3:1 ratio he found, although in an abstract way.

not relevant

Furthermore, the fact that Mendel wrote homozygotes as A instead of AA has no effect at all on the 3:1 ratio. This is because a homozygote (a 'pure' plant) produces only one type of gamete (by definition). An identical pair still produces one type of gamete. From our present-day perspective, a homozygote is diploid, has a pair of identical alleles, and so Mendel used a 'wrong' notation, but in the context of the ratios this does not make a

difference. The crucial assumption here is that the hybrid has a pair of factors. Of course Mendel could not miss that, because A and a are a pair. Therefore, Waller is imprecise in claiming that it is unreasonable that Mendel could not have inferred a pair. Mendel could not prove that homozygotes have a pair. However, he did not need such a proof. And this is not because he could not see chromosomes, but because it was not necessary to explain his 3:1 ratio. And because he did not need it, it was no hindrance for the full explanation of the ratio. According to geneticist C. D. Darlington, Mendel evaded the unproved doubleness of the homozygotes. Mendel's successors made the next step and described the homozygotes as AA. "A step Mendel himself would no doubt have made had he ever met a single person with whom he could seriously discuss his ideas" (14). It seems that Darlington was the only geneticist who correctly read Mendel's paper (independently of Olby).

no explantion? only descriptive?

I strongly disagree that Mendel's work was 'purely a descriptive exercise'. Mendel's statement "The internal composition of the egg and pollen cells of hybrids" is beyond pure description. One cannot see the 'internal composition' of eggs. It is an inference. Of course Mendel did not believe that green or yellow colours were somehow present in seed. Mendel certainly tried to explain his observed ratios by a hypothetical unobservable internal composition of egg and pollen. Of course he could not see the presence of the recessive factor in a hybrid with a dominant phenotype. It is also an inference. Waller does not mention Mendel's manipulation of data (2) (a lost opportunity!). If Mendel had no expectations about 'correct' ratios, how could he or his assistant consciously or unconsciously 'correct' his data?

Richard Dawkins about Mendel
It is very instructive and sometimes amusing to compare what Dawkins (3) says about Darwin and Mendel and what Waller says. "Fisher cleverly remarked that Mendelism has a kind of necessary plausibility which could have led to its discovery by any thinker in a mid-Victorian armchair". Well, Mendel could not according to Waller! Fisher should have added 'once you *know* the solution and all the supporting evidence'! Darwin himself did hybridisation experiments and counted the different forms in the progeny, but did not infer Mendel's laws (10). Dawkins did not explain why it was so plausible and which assumptions go into it. Secondly, did Darwin know about Mendel's publication? Opinions differ. Some sources say YES, Dawkins says NO. If Darwin was so close, and could use non-blending inheritance so desperately, why did he not embrace non-blending inheritance? Why did Darwinists not use Mendelism immediately after the rediscovery? Why did it have to wait until the 1930's that Mendelism was integrated into evolutionary theory?

Ernst Mayr about Mendel
It is always interesting to find out what Mayr wrote about a subject. Mayr (4) states that the outstanding contribution made by Mendel was the refutation of the idea that many replicas of a single determinant are transmitted simultaneously to the germ cells and instead that such factors exist always in pairs. Mayr went even further: the 3:1 ratio *requires* that characters exists in pairs! According to Mayr, Mendel inferred that each character is represented in a fertilised egg by *two and only two* factors from his 3:1 ratios. Amazingly, this is exactly what Mendel failed to do according to Waller! Even more amazingly, Mayr knows about the historical source (Olby,1979) that first pointed out the deficiencies in Mendel's knowledge.

Peter Bowler about Mendel
Bowler is known for his excellent history of Darwinism (5). He accepts the possibility that Mendel did not think of paired particles. Mendel intended his work as a contribution to the origin of species by means of hybridisation (just as Linnaeus); not as a contribution to pure genetics. Therefore Mendel was opposed to Darwin. Bowler agrees with Waller, but with the important difference that Bowler is more careful, while Waller expresses his opinions without reservations.

what did the rediscovers rediscover?

If one concludes, as I do, that the cytological evidence in 1900 was too incomplete to support allelic pairs and that the logic of the ratios alone should be enough to infer allelic pairs for both homozygotes and heterozygotes, the question arises: what exactly did the rediscoverers rediscover? Only Mendel's ratios or the correct interpretation too? It is perfectly possible that they only reproduced the Mendelian ratios in 1900. One needs to investigate how they described their homozygotes. Did they

write AA in 1900 or was it a few years later when cytological evidence became convincing enough?

historical lessons

I agree with Waller that geneticists after the rediscovery of Mendel have interpreted Mendel with the benefit of hindsight and in doing so obscured Mendel's struggle with the correct interpretation of his data (13). We now have a more realistic view of Mendel's achievement. But more importantly, instead of undermining the genius of Mendel, historical research gives us insights in the intellectual struggle of those who made scientific revolutions. We gain insight in how scientific discoveries are made. If anybody is to blame it is not Mendel but those who misinterpreted him. On the other hand, if historical accuracy is sacrified for the sake of efficient training in genetics, then this seems harmless efficiency. A general conclusion is that revolutionary ideas never come fully formed. Even when we view an ingredient (allelic pairs) of a conceptual system (Mendelian genetics) as logically necessary today, it is possible that it is not present in the theory of the inventor.

Genetics: paradigm of successful science

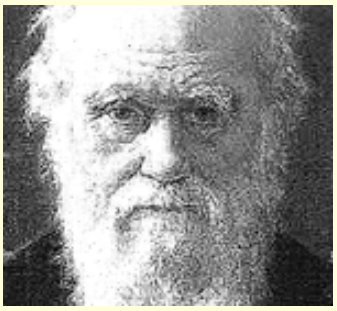
It is beyond Waller's scope that the development of genetics as a science is the prime example of progress in biology. The development of the concept of the gene from an abstract speculative entity to a physical object that can be manipulated in a test-tube, is a paradigm of successful science. Even the in the flourishing period of classical Mendelian genetics, 1900 - 1950, the gene was an abstract theoretical entity. The physical basis of the gene was established by the landmark paper of Watson & Crick in 1953.

Modern genetics is a synthesis of the disciplines Mendelian genetics, population genetics, cytogenetics, molecular genetics, genomics and more. Genetics is at the centre of modern biology and it has achieved an unparalleled unifying power for all biological disciplines. Viewed from this perspective, the progress since Mendel is even the more impressive and the few shortcomings of Mendel are insignificant. Mendel was the first to carry out genetic experiments systematically and on a large scale. My claim is that there is no other way to start the science of genetics. Mendel still is the founder of genetics, despite his minor shortcomings.

Even a discipline traditionally separated from biology and genetics, such as pharmacology, is now witnessing a merger with genetics resulting in the disciplines pharmacogenetics and pharmacogenomics. Another example: during the past few years the fastest growing and most influential trend in memory research has been the molecular genetic apporach. (12)

Decade of the Brain:
In 2003 neuroscience and genomics teamed up in projects that promise to propel the study of the brain into the real of 'big science'. This is another example how genetics proves its central position and its revolutionary role in biology (18)

Darwin: a lifelong Lamarckist



Typically, the chapter about Charles Darwin is called "The origin of species by means of use-inheritance". A subtle hint to Darwin's lifelong Lamarckism!

Waller attacks four Darwinian myths:

- myth 1: Darwin's theory of evolution was original and a complete break with the past.
According to Waller "Historians now recognise that the core principles of evolution - struggle for survival, selection, heritability, adaptation, even the appearance of random changes to the hereditary makeup - were fairly common themes in Victorian botany and zoology." I have no problem in searching for historical forerunners of Darwin, and pointing out misconceptions, but the result seems to be that the Darwinian revolution becomes a mystery. If every ingredient of evolution was there, what did Darwin do? Was there a revolution at all? It looks as if Waller's main goal is to destroy all the originality of Darwin. One could as well claim that Shakespeare was not very original because he only arranged existing words in a particular order.

- myth 2: The great achievement of Darwin was that he replaced Lamarckian inheritance of acquired characteristics with random variations and natural selection.
  Waller claims that Darwin believed in Lamarckian inheritance of acquired characteristics during all the subsequent editions of the Origin. However, even the historian of science Peter Bowler has a more balanced view: "Darwin himself accepted that the inheritance of acquired characters might supplement natural selection and his view of heredity allowed for the effect to occur" (5, p. 236).
  According to Strickberger "at times Darwin accepted the Lamarckian view of the inheritance of use and disuse"
- myth 3: Darwin treated the causes of variation as a black box because he had no good theory of heredity.
  According to Waller, Pangenesis was very good science! Darwin 'knew' how new genetic variation was produced, it was not a black box for him. A non-blending theory of inheritance was readily available to Darwin. His cousin Francis Galton developed an ingenious particulate theory of heredity.
- myth 4: Darwin consistently claimed that evolution is not progressive.
  Waller claims that Darwin believed in progressive evolution, but he does not give good evidence for his claim.

The two chapters about Darwin deserve a careful reading. Some general conclusions can be drawn. Because the previous generation had incomplete knowledge, we automatically fill in the gaps when we describe their knowledge. In our time we know more than they did. But we also are inclined to ascribe some of the solutions of the puzzle to our ancestors, because we know they are logically necessary. Mendel and Darwin are not accused of scientific misconduct; they are simply not as good, and not as revolutionary as modern scientists claim.

Huxley and others

Waller describes Huxley as creating a war between science and religion. Huxley fought a war against religion to further his personal career in science. Huxley believed science and religion are incompatible and Waller clearly dislikes the idea. Waller himself seems to be in favour of the idea that science and religion are compatible. Further, he seems to have some sympathy for the creationist position (see also his mild judgement of creationist Pasteur). In a chapter about using anaesthetics in medicine (Ch 13) Waller states that "White's science-religion dichotomy was being talked into existence" (6).
Other scientists such as physicists Eddington and Millikan have manipulated their experimental data (data suppression: throwing away what you don't like). How can you ever trust a high ranking and influential physicist after reading this? This is good material to study the complexities of how a scientific theory is proved or disproved.

Waller has done great service to busy readers interested in the scientific method, scientific controversies, and the history of science by summarising many books and articles in the recent history of science. The result is an introduction to a diversity of issues from a diversity of disciplines one would otherwise not have encountered.
Waller's claim that Mendel did and could not understand Mendelian genetics is wrong. Mendel's explanation for the ratio's is correct despite his puzzling notation and despite his lack of cytological knowledge. It seems that Waller himself failed to understand the full force of the logic of the Mendelian ratio's.

Notes

1. John Galloway: Airbrushing science. *Nature* **422**, 19-20 (2003) 6 March 2003. (is a review of the book).
2. R. A. FISHER Has Mendel's Work Been Rediscovered?, From Annals of Science, 1 (1936).
3. Richard Dawkins(2003) A Devil's Chaplain. Selected Essays by Richard Dawkins, p.68.
4. Ernst Mayr(1982) The Growth of Biological Thought, p.720,721
5. Peter Bowler(2003) The history of an idea, third edition, p.262.
6. On page 281 White's work is "History of the Conflict Between Science and Religion"; and on page 282,283 it is "Warfare of Science with Theology". According to Arthur Strahler the work was first published in 1896 and

reprinted in 1978. Another reference is: Arnold D White (1898) "History of the warfare of Science and with Theology in Christendom".

7. Srb, Owen, Edgar (1965) General Genetics, p.34
8. Franklin Portugal and Jack Cohen (1977) "A Century of DNA. A History of the Discovery of the Structure and Function of the Genetic Substance", p. 115 (emphasis is mine).
9. Recently, James Gleick added Newton to this hero-debunking list: "Newton of all people was no Newtonian". Patricia Fara (2003) "Was Newton a Newtonian?", Science 301 (5635), p.920, 15 Aug 2003.
10. Even more amazing, Enrico Coen mentions in his splendid *The Art of Genes* (244-245) that Darwin did crossings with *Antirrhinum* and reported a ratio of 37 : 127 (1 : 3,4)! Darwin completely missed the importance of this result!
11. Gunther Stent and Richard Calendar(1978) Molecular Genetics. An Introductory Narrative. Second Edition, p.12.
12. Rusiko Bourtchouladze (2003) "Memories are made of this. The Biological Building Blocks of Memory", Phoenix paperback, p. 15. (well written book, agreeable reading)
13. An example is Brian Silver's description of Mendel's discoveries in his *The Ascent of Science* (p.262). After an introductory paragraph about Mendel, he asks "What would *we* expect from these experiments?", thereby completely sidestepping what Mendel wrote! How can one ever discover how scientific discovery works and how scientific revolutions are made? Compare also with Sturtevant below.
14. C.D. Darlington (1966) "Genetics and Man", Penguin Books, p.98.
15. Jan Sapp (2003) "Genesis. The Evolution of Biology", p.89.
16. Jan Sapp does not discuss the possible relation of chromosomes and Mendelian factors at all, although he is interested in cytology. He does not mention the AA or A problem.
17. With the benefit of hindsight the discovery of salivary gland chromosomes showing clear banded strands by Balbiani in 1881 seems highly informative, but they were wrongly interpreted at the time (see Sturtevant book below, page 75).
18. Alison Abbott (2003) Neuroscience: Genomics on the brain, *Nature* **426**, 757 (18 Dec 2003).
19. Stephen Jay Gould (2002) "The Structure of Evolutionary Theory", p.410
20. A.H. Sturtevant (2001) "A History of Genetics", page 49.

Further Reading

- Email from John Waller.
- Waller's home page at the Dept of History and Philosophy of Science of the University of Melbourne, Australia.
- Mendel, Mendelism and Genetics by Robert C. Olby (full text available on the MendelWeb site). In section 3 "Mendel as Founder" Olby points out the absence of double letters to represent the pure breeding individuals. This is the most important fact on which Waller bases his argument. There is also an important paragraph "Mendel and the Darwinians" in which Olby discusses Mendel's ideas about evolution and how Darwinists initially reacted to Mendel. The Mendelweb also contains Mendel's paper.
- **A.H. Sturtevant**(2001) *A History of Genetics*. A paperback reprint of the 1965,1967 edition. The full text of the book is available on-line at the Electronic Scholarly Publishing site, in PDF format. Additionally Mendel's original paper and many other classics in genetics are available. Sturtevant confirms Stent and Calendar's observation that Weismann concluded that each chromosome carries all the hereditary elements necessary to produce a whole individual (p. 19). I could not have imagined this possibility! With our current genetic knowledge it is unthinkable that each chromosome contains the information for a whole individual. For humans it would mean that each gene has 46 copies. This theory clearly

contradicts the idea that each genetic character comes in pairs. There is one remarkable fact about Sturtevant's book: he did not discuss Mendel's paper! How could he have noticed Mendel's inconsistent interpretation when he did not *read* Mendel's paper carefully? It seems Sturtevant is just not interested in how Mendel himself interpreted his results.

- Deviations from Mendel's laws (non-Mendelian inheritance) are discussed in Mark Ridley Mendel's Demon. Gene Justice and the Complexity of Life and Gabriel Dover Dear Mr Darwin. Letters on the evolution of life and human nature on this site.
- Rescue science's history from historians! Pasteur knocked off pedestal? (Nature, free access)
- DNA timeline with cartoons and starting with Mendel...
- **Jan Sapp** (2003) *Genesis. The evolution of Biology*. In other respects this is an interesting history of biology. Sapp discusses non-Darwinian and non-Mendelian mechanisms usually omitted in history of biology textbooks.
- **John Waller** (2003) *Einstein's Luck: The Truth Behind Some of the Greatest Scientific Discoveries* (the USA edition of *Fabulous Science*). Reviewed in American Scientist online issue: January-February 2004.
- **John Waller** (2003) *The Discovery of the Germ. Twenty Years That Transformed the Way We Think About Disease*. Columbia University Press, New York, 2003 Hardback: 205 pp., illus.
- **Elof Axel Carlson** (2004) *Mendel's Legacy: The Origin of Classical Genetics*. Cold Spring Harbor Laboratory Press. Previous histories of classical genetics have highlighted the successes and neglected the failures says geneticist and historian of science E. A. Carlson. There is an enthousiastic review of the book by Garland Allen 'Peas and helices' in *Nature* **430**, 404 22 July 2004
- **John Waller** (2004) *Leaps in the Dark*, Oxford University Press.
    - Review in the NewScientist.com (Dec 2004): "DO YOU think James Lind proved that fruit juice prevents scurvy? That Robert Watson-Watt invented radar? That Isaac Newton showed a prism splitting white light into pure colours? Reader, you are the weakest link in the history-of-science round and must leave the contest. If only you had read John Waller's *Leaps in the Dark*, you would have known better. Like his earlier successful book, *Fabulous Science*, it examines a collection of hoary tales from science's past. All their tellers are convicted of crimes ranging from oversimplification to outright falsehood. Sometimes, as with Watson-Watt or the microbiologist Selman Waksman, credited with discovery of streptomycin, this is due to mere self-promotion. Other cases are due to myth- hignmatt (kam spl03 Htendingrceslection ve)ou a col." (, 404)Tj 1 0 0 rg 6.33046 0 0 61596 0091<</46 0377
