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LORD KELVIN

Fourier believed that the main aim of mathematics should be the understanding of nature and that the purpose of understanding nature should be the benefit of mankind. Yet, interesting though Fourier's own work was, he could point to no direct practical benefit from it. The credit for showing how powerful were the tools that Fourier had forged belongs, above all, to William Thomson, Lord Kelvin.

The life of William Thomson was linked with the University of Glasgow from 1832, when his father became professor there. Thomson was not a late developer. At the age of ten he and his 12-year-old brother enrolled in the University of Glasgow. Prizes in Greek, logic (what we would now call philosophy), mathematics, astronomy and physics marked his progress. 'A boy', he said later, 'should have learnt by the age of twelve to write his own language with accuracy and some elegance; he should have a reading knowledge of French, should be able to translate Latin and easy Greek authors and should have some acquaintance with German.'

Towards the end of his time as a student in Glasgow he fell under the influence of an inspiring physics teacher called Nichol.

> ...after I had attended in 1839 Nichol's... Class, I had become filled with the utmost admiration for the splendour and poetry of Fourier. Nichol was not a mathematician and did not profess to have really read Fourier, but he was capable of perceiving his greatness and of understanding what he was driving at, and of making us appreciate it. I asked Nichol if he thought I could read Fourier. He replied 'perhaps'. He thought the book a work of most transcendent merit. So on the Ist of May the very day when the prizes were given, I took Fourier out of the University Library, and in a fortnight I had mastered it – gone right through it.

(This and the next quotation are from Silvanus P. Thompson's *Life of Lord Kelvin.*)

At the age of seventeen Thomson entered Cambridge University. (It was not uncommon for good students to first study at a Scottish University and then transfer to Cambridge. A cynic might say that people like Maxwell and Thomson were educated in Scotland and examined in Cambridge.) The examinations in Cambridge were fiercely competitive exercises in problem solving against the clock. The best candidates were trained as for an athletics contest. Thomson's coach might declare that his candidate had mathematical abilities which would outshine any man in England but the coach of Thomson's rival boasted, more pertinently, that he had a candidate who could beat any man in Europe in an examination. Thomson (like Maxwell later) came second. During his time in Cambridge he had however won the Colquhoun sculls as a rower, published sixteen papers and, most important of all, obtained from his coach, a day before he left, two copies of Green's *Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism.*

Thomson's father had by now conceived the ambition of seeing his son elected to a chair in Glasgow. To improve his chances he was sent to France to learn experimental work in the laboratory of Regnault, to meet as many influential people as possible and, since the electors would place great emphasis on teaching ability, to learn the art of giving popular lectures. Thomson's abilities won him a ready welcome and his copies of Green's *Essay* created a great stir.

> Eager steps were heard without and with a hasty rap upon the door a panting visitor rushed in. It was Sturm, in a state of high excitement. 'Vouz avez le Mémoire de Green', he exclaimed, 'M. Liouville me l'a dit!'. The *Essay* was produced, and Sturm eagerly scanned its contents, turning over page after page. 'Ah voilà mon affaire', he cried, jumping from his seat as he caught sight of the formula in which Green had anticipated his theorem of the equivalent distribution.

The methods of Green and Fourier formed the foundation of Thomson's mathematical methods. The foundations for his deepest physical insights were laid in Paris. Liouville encouraged him to investigate the relation between Faraday's 'lines of force' view of electrical phenomena and the classical continental 'action at a distance', and, by reading Clapeyron, he became aware of Sadi Carnot's view of heat.

Meanwhile his father's campaign had borne fruit and at the age of twenty two, swept in on a wave of testimonials from, among others, De Morgan, Cayley, Hamilton, Boole, Sylvester, Stokes, Regnault and Liouville, Thomson became Professor of Natural Sciences at the University of Glasgow. Nor were his sponsors mistaken. For the next 20 years Thomson was to dominate physics.

There is a curious anonymity about physical ideas which makes it difficult to appreciate fully the originality of their discoverers. A novel always retains the signature of its author, a proof in pure mathematics may still delight us by its ingenuity or power after a hundred (consider Liouville's proof given as Theorem 38.2 of the existence of transcendental numbers) or a thousand years (consider Euclid's proof that there exist an infinity of primes), but the physics breakthrough of today is the common sense of tomorrow.

In electricity Thomson provided the link between Faraday and Maxwell. He was able to mathematise Faraday's laws and to show the formal analogy between problems in heat flow and electricity. Thus the work of Fourier on heat immediately gave rise to theorems on electricity and the work of Green on potential theory immediately gave rise to theorems on heat flow. Similarly methods used to deal with linear and rotational displacements in elastic solids could be applied to give results on electricity and magnetism.

Maxwell, who from the end of his undergraduate days conducted a constant correspondence with Thomson first as pupil to master and then as equal to equal, felt sure that Thomson must have a complete theory of electrodynamics 'lying in loose papers and neglected only till you have worked out Heat or got a little spare time'. (The correspondence was published as *Origins of Clerk Maxwell's Electric Ideas*, Larmor, Cambridge University Press, 1937. It includes a useful note from Maxwell on the habits of peacocks.) However, Thomson did not have such a theory and could never fully accept Maxwell's ideas.

Thomson's other major contribution to fundamental physics was his combination of the almost forgotten work of Carnot with the work of Joule on the conservation of energy to lay the foundations of Thermodynamics. Thomson himself was particularly proud of an argument developed with his brother which predicted the fall in the freezing point of water under pressure.

Other discoveries and inventions of Thomson are dealt with elsewhere in this book. We note in passing the discovery of what is now called Stokes' theorem and the first mathematical discription of the oscillation of an electric circuit. After his work on the Atlantic cables (to be described in Chapters 65 and 66) he turned increasingly towards the practical applications of physics. He acted as consultant engineer to undersea telegraph and overland electric power transmission schemes (for example he worked out the optimum diameter of a transmission line). He was also unsurpassed as a designer of the rugged but accurate instruments required by the new electrical industries and took an active part in running the firm of Kelvin and Wright which manufactured them.

As a teacher he was inspiring rather than methodical. By a tradition which he supported, his audience included non specialists such as future doctors and theologians. Since he refused to talk down to his audience, some of them may not have understood very much but they all appreciated that they were being taught by a great man. Particularly enjoyed were lectures on acoustics (illustrated by a performance on the French horn), impulse (in which a large rifle was fired at a ballistic pendulum) and an experiment in which a large rubber sheet was slowly filled with water until it burst.

His teaching laboratory was the first in Britain. (The proposal to introduce experimental work into the Cambridge undergraduate courses aroused strong opposition. 'If [the student] does not believe the statements of his tutor – probably a clergyman of mature knowledge, recognised ability and blameless character – his suspicion is irrational and manifests a want of the power of appreciating evidence, a want fatal to his success in that branch of science which he is supposed to be cultivating.' (Todhunter, First essay in '*The Conflict of Studies*', Macmillan 1873; since Todhunter is no fool the essay is worth reading.))

In conjunction with his friend Tait he wrote the famous *Thomson and Tait* (or *T* *and T'* as it was known by everybody from Maxwell downwards) *Treatise on Natural Philosophy*. Originally intended as three moderately sized volumes which would cover all of mathematical and experimental physics, it became, as these things tend to become, two large volumes on mechanics.

As Maxwell said in his review of the second edition, the great merit of this work lay in rescuing a large chunk of physics from the mathematicians. Thanks to Thomson and Tait

> dynamical theorems have been dragged out of the sanctuary of profound mathematics in which they lay so long enshrined and have been set to do all kinds of work easy as well as difficult, throughout the whole range of physical science,....
>
> The two northern wizards were the first who, without compunction or dread, uttered in their mother tongue the true and proper names of those dynamical concepts which the magicians of old were wont to invoke only by the aid of muttered symbols and inarticulate equations. And now the feeblest among us can repeat the words of power and take part in dynamical discussions which but a few years ago we should have left for our betters.
>
> (*Maxwell's Collected Works, p. 782, Vol.* I.)

As in mechanics so elsewhere Thomson's career marked the break away of mathematical physics and mathematical engineering from mathematics into separate disciplines with their own methods and ideas. Thomson's contemporaries considered him almost a second Newton, but he would, I think, have been happy with the modern estimate of him as Fourier's successor and (with Faraday) Maxwell's predecessor.

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THE AGE OF THE EARTH I

It is a very natural assumption that the earth and the species on it, including man, were all created at the same time. The age of the earth would then be approximately the length of man's recorded history, a few thousand years, and its geography and landscape essentially unchanged since the beginning.

However in the first decades of the nineteenth century geological evidence for great changes in the past began to build up. Large areas of land had once been under water, mountain ranges had been thrown up from lowlands and the evidence of fossils showed the past existence of species with no living counterparts.

At first it seemed that such vast changes must have been the outcome of tremendous and violent forces. According to this view the world that we live in has been shaped by a series of cataclysms (the last of which was often identified with Noah's flood) and the age of the earth must be reckoned in tens of thousands of years.

However Lyell in his *Principles of Geology* presented detailed and convincing arguments for an opposing view. He sought to 'explain the former changes by causes now in operation'. According to his theory processes such as slow erosion by wind and water, gradual deposition of sediment by rivers and the cumulative effect of earthquakes and volcanic action combined over very long periods of time to produce the vast changes recorded in the earth's surface.

Lyell's theory was called 'uniformitarian' because it rejected the idea that geological processes had been more violent in the past than they are today. But the rejection of vast forces was only made possible by the acceptance of vast times. The rate of action of very slow forces is, obviously, very hard to measure but uniformitarian theories demanded that the age of the earth be measured certainly in terms of millions of years, probably in hundreds of millions, perhaps in thousands of millions of years or more.

Lyell was unable to produce a uniformitarian biological theory to complement his uniformitarian geological theory. He was able to account for the disapperance of species in the geological record but not for the emergence of new species. A solution to this problem was provided by Darwin with his theory of evolution by natural selection.

Darwin's theory too, required a geat age for the earth. 'He who can read Sir Charles Lyell's grand work on the Principles of Geology,... yet does not admit how incomprehensible vast has been the past period of time, may at once close this volume' (Darwin, *On the Origin of Species*, First Edition, *p.* 282). To allow time for natural selection to operate, the age of the earth must be measured in many hundreds of millions of years.

But such demands for endless time run counter to the laws of thermodynamics. Every day the sun radiates immense amounts of energy. By the law of conservation of energy there must be some source of this energy and when the source is exhausted the process must cease. Kelvin, as one of the founders of thermodynamics, was fascinated by this problem. Simple calculation shows that chemical processes (such as in the burning of coal) are totally insufficient as a source and he was forced to conclude that the only available mechanism was the conversion of gravitational potential energy into heat as the sun contracted.

On this assumption his calculations showed that '[it is] on the whole most probable that the sun has not illuminated the earth for 100 000 000 years and almost certain that [it] has not done so for 500 000 000 years'. Moreover, Kelvin believed that the sun was cooling so that the climate would become more extreme (and the associated geological processes more violent) as we go back in history.

However, Kelvin's most compelling argument, though still based on the principle of conservation of energy, concerned the earth rather than the sun. It is well known that the temperature of the earth increases with depth and

> this implies a continual loss of heat from the interior, by conduction outwards through or into the upper crust. Hence, since the upper crust does not become hotter from year to year there must be a... loss of heat from the whole earth. It is possible that no cooling may result from this loss of heat but only an exhaustion of potential energy which in this case could scarcely be other than chemical.

But there is no reasonable mechanism to keep a chemical reaction going at a steady pace for millions of years so, Kelvin concludes, 'the... view... that the earth is merely a warm chemically inert body cooling, is clearly to be preferred in the present state of science'. (The quotations are from Appendices D and E of Thomson [Kelvin] and Tait '*Treatise on Natural Philosophy*'.)

However high the initial temperature of the earth, geological history could only begin when the outer crust had solidified. Did the earth solidify first from the outside leaving a liquid core or did convection currents ensure that the earth solidified at a uniform temperature throughout? Many early Victorian geologists pictured the earth as a molten mass on which floated a thin skin of solidified rock and this plausible picture survives in the popular mind today. However, Kelvin and others had already shown that such a picture was dynamically inconsistent with known facts. (Indeed, Kelvin's computations revealed a body with the rigidity of a steel ball of similar size.) The rejection of this model together with the fact that molten rock contracts on solidifying led Kelvin to believe that the earth was a solid body and that it had solidified at a more or less uniform temperature. In the next chapter we shall see how, starting from this hypothesis, he was able to estimate the age of the earth.

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THE AGE OF THE EARTH II

Let us examine the mathematical consequences of Kelvin's model of a cooling earth. We take the earth to be the sphere $\{\mathbf{x}:|\mathbf{x}|<R\}$ and write the temperature at a point $\mathbf{x}$ and time t as $\psi(\mathbf{x},t)$. Assuming the composition of the earth to be, roughly, homogeneous the temperature distribution will be governed, roughly, by Fourier's heat equation

$$\frac{\partial\psi}{\partial t}(\mathbf{x},t)=K\nabla^2\psi(\mathbf{x},t).$$

We have already decided to take the initial temperature (at time $t=0$ say) to be constant,

i.e.

$$\psi(\mathbf{x},0)=\theta_0 \quad \text{for all } |\mathbf{x}|<R,$$

but we still have to decide on our other boundary condition. Kelvin gives several convincing arguments for the choice

$$\psi(\mathbf{x},t)=C \quad \text{for all } |\mathbf{x}|=R,\, t>0,$$

where C is a constant and it is, of course, part of the uniformitarian position that the temperature of the earth's surface has not fluctuated very much during geological time. (This is even more important to the biological than to the geological theory. If the climate became too hot or too cold life would be wiped out.) Choosing a suitable temperature scale we may simplify the last equation by setting $C=0$ to obtain

$$\psi(\mathbf{x},t)=0 \quad \text{for all } |\mathbf{x}|=R,\, t>0.$$

The equations for a cooling sphere set out above are not difficult to solve and Kelvin had already solved them in a different context. But preliminary calculations show that the cooling effect for the earth can still be only skin deep. (That is to say that, at depths small compared with the radius of the earth, $\psi(\mathbf{x},t)$ is, at the present time, very close to its initial value ψ_0.) Under these circumstances the mathematics becomes easier to interpret if we neglect the curvature of the earth. Writing $\theta(y, t)$ for the temperature of the earth at depth y and time t our problem then reduces to the one dimensional problem

$$\frac{\partial\theta}{\partial t}(y,t) = K\frac{\partial^2\theta}{\partial y^2}(y,t) \quad \text{for all } y>0, t>0,$$
$$\theta(y,0)=\theta_a \quad \text{for all } y>0,$$
$$\theta(0,t)=0 \quad \text{for all } t>0.$$

We shall solve these equations by using the results of Chapter 55 together with one of Kelvin's favourite mathematical tricks – the method of images. A vivid illustration of the method of images is given by the following example. Suppose we wish to find the behaviour of a plume of smoke from a tall factory chimney set in the middle of a large plane (see Figure 57.1). In addition to the general equations describing the behaviour of the smoke we must satisfy a boundary condition which states that smoke cannot pass through the ground.

To get round this problem we consider a reflected factory chimney producing a reflected plume of smoke as shown (Figure 57.2). There will then be no net flow

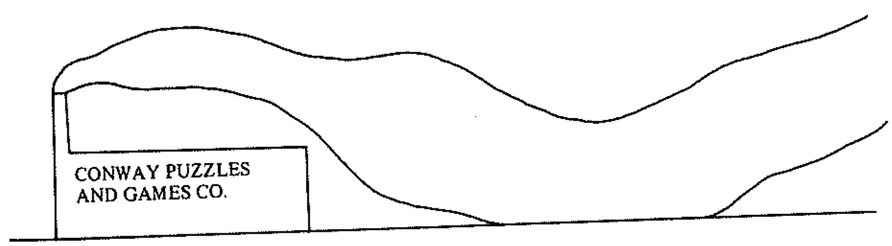

Fig. 57.1. The problem of the smoke plume.

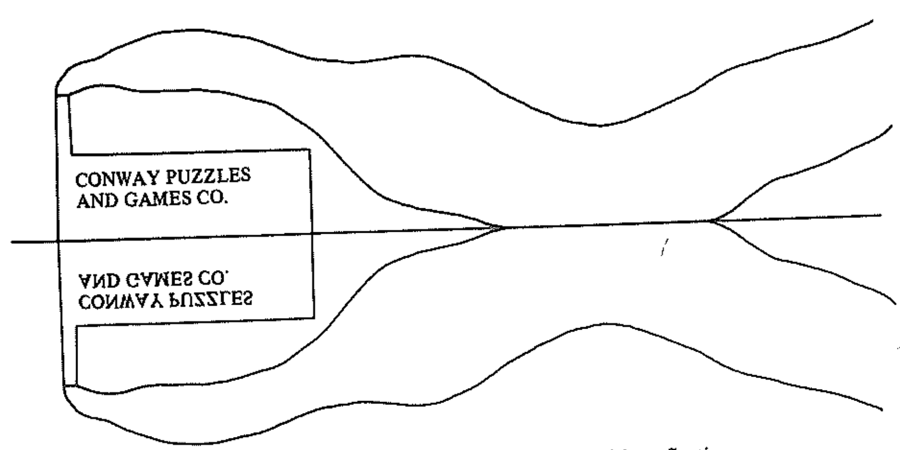

Fig. 57.2. The problem of the smoke plume and its reflection.

of smoke across the plane of reflection and the upper half of the solution to the new problem will correspond to the solution of our original problem.

Using a similar idea we obtain the following result.

Lemma 57.1. *Let $\theta_0 \in \mathbb{R}$ and*

$$\theta(y,t) = \frac{\theta_0}{2\sqrt{(\pi K t)}} \int_0^\infty \left\{ \exp\left(-\frac{(y-w)^2}{4Kt} \right) - \exp\left(-\frac{(y+w)^2}{4Kt} \right) \right\} dw$$

for all $y \geq 0$, $t > 0$. Then $\theta: [0, \infty) \times (0, \infty) \to \mathbb{R}$ is an infinitely differentiable function with

(i) $(\partial\theta/\partial t)(y,t) = K(\partial^2\theta/\partial y^2)(y,t)$,
(ii) $\theta(y,t) \to \theta_0$ *as* $t \to 0+$ *for all* $y > 0$,
(iii) $\theta(0,t) = 0$ *for all* $t > 0$.

Proof. Let

$$G(x) = \theta_0 \quad \text{for } x > 0,\ G(0) = 0$$

and

$$G(x) = -\theta_0 \quad \text{for } x < 0.$$

Then, taking

$$\phi(x,t) = G * E_{1/\sqrt{(2Kt)}}(x) \quad \text{for } x \in \mathbb{R},\ t > 0,$$

we know from Lemma 55.6 that ϕ is an infinitely differentiable function on $\mathbb{R} \times \mathbb{R}^+$ with

(i)′ $\partial\phi/\partial t = K(\partial^2\phi/\partial x^2)$,
(ii)′ $\phi(x,t) \to G(x)$ for all $x \in \mathbb{R}$ as $t \to 0+$.

By symmetry we have $\phi(x,t) = -\phi(-x,t)$ for all $x \in \mathbb{R}$ and so in particular

(iii)′ $\phi(0,t) = 0$ for all $t > 0$.

We observe that

$$\begin{aligned}
\phi(x,t) &= \frac{1}{2\sqrt{(\pi K t)}} \int_{-\infty}^{\infty} G(w) \exp\left(-\frac{(x-w)^2}{4Kt} \right) dw \\
&= \frac{\theta_0}{2\sqrt{(\pi K t)}} \left(\int_0^\infty \exp\left(-\frac{(x-w)^2}{4Kt} \right) dw - \int_{-\infty}^0 \exp\left(-\frac{(x-w)^2}{4Kt} \right) dw \right) \\
&= \frac{\theta_0}{2\sqrt{(\pi K t)}} \left(\int_0^\infty \exp\left(-\frac{(x-w)^2}{4Kt} \right) - \exp\left(-\frac{(x+w)^2}{4Kt} \right) dw \right),
\end{aligned}$$

and so by inspection ϕ is real valued. Setting $\theta(y,t) = \phi(y,t)$ for all $y \geq 0$, $t > 0$ the stated result follows. ∎

Ignoring questions of uniqueness as physically irrelevant we have thus obtained the temperature of the earth at depth y and time t in the form

$$\theta(y,t) = \frac{\theta_0}{2\sqrt{(\pi K t)}} \left(\int_0^\infty \exp\left(-\frac{(y-w)^2}{4Kt} \right) - \exp\left(-\frac{(y+w)^2}{4Kt} \right) dw \right).$$

We can make no direct measurements of the earth's temperature at great depths but we can measure the rate of increase of underground temperature as we mine deeper into the earth's crust. Our interest is therefore in

$$\frac{\partial\theta}{\partial y}(0,t)=\left[\frac{\theta_0}{2\sqrt{(\pi K t)}}\int_0^\infty -\frac{2(y-w)}{4Kt}\exp\left(-\frac{(y-w)^2}{4Kt}\right)\right.$$
$$\left.+\frac{2(y+w)}{4Kt}\exp\left(-\frac{(y+w)^2}{4Kt}\right)dw\right]_{y=0}$$
$$=\frac{\theta_0}{2\sqrt{(\pi K t)}}\int_0^\infty \frac{w}{Kt}\exp\left(-\frac{w^2}{4Kt}\right)dw$$
$$=\frac{\theta_0}{\sqrt{(\pi K t)}}\left[-\exp\left(-\frac{w^2}{4Kt}\right)\right]_0^\infty=\frac{\theta_0}{\sqrt{(\pi K t)}}$$

(so that, writing $v=(\partial\theta/\partial y)(0,t)$, we have

$$t=\theta_0^2(\pi K)^{-1}v^{-2}).$$

(This result could also have been obtained using Lemma 55.7 (ii).)

If the earth is indeed more or less homogeneous then the conductivity K and melting point θ_0 can be determined by measurements on samples of surface rock whilst measurements in mines or special borings will give v. Taking the best available measurements Kelvin arrived at an estimate of 100 000 000 years as the age of the earth. Even allowing for uncertainties in his data, he felt confident that the age of the earth could not be more than 400 000 000 years old and his calculations of the sun's age referred to in the last chapter confirmed that an age of 100 000 000 years was more likely.

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THE AGE OF THE EARTH III

The reception of Kelvin's calculations is described by J.D. Burchfield in his very interesting book *Lord Kelvin and The Age of the Earth* (Macmillan, 1975) on which this chapter is based. Before Kelvin few geologists had thought deeply about the problem of geological time partly from lack of data but mainly perhaps because the human mind finds it hard to contrast a vast time of ten million years with a vast time of a thousand million years.

As the force of Kelvin's argument sank in, geologists began to examine their uniformitarian theories more critically. Certainly if the rate of geological change had been the same throughout geological history as that observed today, 100 000 000 years would not suffice to shape the present state of the earth's surface. But as Kelvin himself pointed out, if the earth is losing energy then in earlier times geological forces like earthquakes and volcanoes were probably much more violent. Thus by modifying uniformitarian theory so as to allow past geological forces, though still the same in kind, to be different in degree from those observed today it was possible to speed up the rate of geological change in the past and compress the earth's geological history into Kelvin's 100 000 000 years.

The problems posed to Darwin's theory of evolution by natural selection were more serious. 'I am greatly troubled at the short duration of the world according to [Kelvin], for I require for my theoretical views a very long period before the Cambrian formation (Darwin quoted in Burchfield, p. 75).' In the fifth edition of *The Origin of Species*, Darwin attempted to adjust to the new time scale by allowing greater scope for evolution by processes other than natural selection. He also pointed out that more extreme geological conditions might increase the pressures of natural selection and so increase the rate of evolution.

But in the end he was forced to ask for a suspension of judgement. In the final chapter of *The Origin of Species* in which Darwin reviewed the argument of his book he now added the following words.

> With respect to the lapse of time not having been sufficient since our planet was consolidated for the assumed amount of organic change, and this objection, as

argued by [Kelvin], is probably one of the gravest yet advanced, I can only say, firstly that we do not know at what rate species change as measured by years, and secondly, that many philosophers are not as yet willing to admit that we know enough of the constitution of the universe and of the interior of our globe to speculate with safety on its past duration.

(Darwin *The Origin of Species*, Sixth Edition, p. 409.)

Kelvin reinforced his case with a third argument drawn from the tidal retardation of the earth's rotation. But here he exposed the chief weakness of his arguments. Huxley was able to quote Laplace, Adams and earlier work of Kelvin himself as disagreeing both about the cause and the extent of this supposed phenomenon.

I do not presume (Huxley wrote) to throw the slightest doubt upon the accuracy of any of these calculations made by such distinguished mathematicians as those who have made the suggestions I have cited. On the contrary, it is necessary to my argument to assume that they are all correct. But I desire to point out that this seems to be one of the many cases in which the admitted accuracy of mathematical processes is allowed to throw a wholly inadmissible appearance of authority over the results obtained by them. Mathematics may be compared to a mill of exquisite workmanship, which grinds you stuff of any degree of fineness; but nevertheless, what you get out depends on what you put in; and as the grandest mill in the world will not extract wheat-flour from peascods, so pages of formulae will not get a definite result out of loose data.

(*Quarterly Journal of the Geological Society of London*, Vol. 25, 1869)

However Kelvin's estimates were the best available and for the next thirty years geology took its time from physics, and biology its time from geology. Tait only echoed the general opinion when he wrote: 'Let us then hear no more nonsense about the interference of mathematicians in matters with which they have no concern; rather let them be lauded for condescending from their proud preeminence to help out of the rut the too ponderous waggon of some scientific brother (quoted in Burchfield, p. 93.).'

But even as the geologists readjusted their time scales to fit Kelvin's first estimate for the age of the earth, he and his followers began to adjust it down until at the end of the nineteenth century the best physical estimates of the age of the earth and sun were about 20 million years whilst the minimum the geologists could allow was closer to Kelvin's original 100 million years.

Then in 1904 Rutherford announced that the radio-active decay of radium was accompanied by the release of immense amounts of energy and speculated that this could replace the heat lost from the surface of the earth. Kelvin's argument would then only give a minimum for the earth's age. 'The discovery of the radio-active elements... thus increases the possible limit of the duration of life on this planet, and allows the time claimed by the geologist and biologist for the process of evolution. (Rutherford quoted in Burchfield, p. 164.)'

Rutherford was fond of recounting the story of his lecture to the Royal Institution,

> I came into the room which was half dark, and presently spotted Lord Kelvin in the audience and realised I was in for trouble at the last part of the speech dealing with the age of the earth, where my views conflicted with his. To my relief, Kelvin fell fast asleep, but as I came to the important point, I saw the old bird sit up, open an eye and take a baleful glance at me! Then a sudden inspiration came, and I said Lord Kelvin had limited the age of the earth, *provided no new source of heat was discovered.* That prophetic utterance refers to what we are now considering tonight, radium! Behold! the old boy beamed upon me.
>
> (Eve *Rutherford*, Macmillan 1939, p. 107.)

A problem for the geologists was now replaced by a problem for the physicists. How could the principle of conservation of energy be reconciled with the immense release of energy which occurs in radioactive decay? The answer was provided by a theory which was just beginning to be gossiped about. 'One day... Rutherford began twitting Wien about relativity. Wien explained that Newton was wrong in the matter of relative motion, which was not the joint velocities $u + v$, but that expression, according to Einstein must be divided by $1 + uv/c^2$. Wien added, "But no Anglo Saxon can understand relativity!" "No!" laughed Rutherford, "they have too much good sense" (Eve, p. 193).' Einstein's theory of relativity extended the principle of conservation of energy by taking matter as a form of energy. It is the conversion of matter to heat which maintains the earth's internal temperature and supplies the energy radiated by the sun.

Radio-active dating now leads geologists to give the earth an age of about two or three thousand million years. Indeed they now have so much time that they believe that the present day must be a period of particularly intense geological activity. And in this way Darwin's theories have received a remarkable confirmation.