Science in the Scottish Enlightenment

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Introduction

Inspired by the Scientific Revolution of the seventeenth century, the intellectuals of eighteenth-century Europe launched a dazzling programme for the extension of knowledge and for the promotion of human welfare. Their programme has become known as the 'Enlightenment' and their age is often called the 'Age of Enlightenment'.

This course is concerned with science in Scotland, one of the most dynamic centres of Enlightenment thinking. Writers speak of the mid-eighteenth century as Scotland's 'Golden Age'. In order to get the flavour of this age, it is necessary to take a very broad view of what we mean by 'science'. If we stay within the boundaries recognised by modern science faculties, we will miss most of what is distinctive about eighteenth-century Scotland. The interconnections and cross-fertilisation between disciplines that we now regard as having little to do with each other is one of the remarkable features of the Scottish scene. Geologists associated with historians, economists with chemists, philosophers with surgeons, lawyers with farmers, church ministers with architects.

This OpenLearn course provides a sample of Level 2 study in Arts and Humanities.

Learning Outcomes

After studying this course, you should be able to:

- understand developments in Scotland with regard to the Enlightenment period
- give Scottish examples from the community of philosophers and scientists from the Enlightenment period
- describe how these Scots helped influence the Industrial Revolution and the American Revolution.

1 The Enlightenment in Scotland

The Enlightenment was a programme, rather than a set of completed achievements. Enlightenment thinkers produced few theories comparable with Copernicus's or Newton's in former centuries, or with Darwin's in the next. What makes them memorable is the vigour and confidence of their conviction that the universe – from the orbits of the planets to the workings of the human mind and of human society – is explicable, regular and lawlike, and will yield to the systematic application of rational, empirical, scientific procedures.

Enlightenment thinkers attempted to extend the realm of lawlike regularities beyond the physical sciences into biology, geology, medicine, psychology, politics, economics, history. Indeed, *wherever* knowledge was to be gained, it had to be scientific, empirical knowledge: it was the only sort that counted. Moreover, this knowledge, however abstract, should graduate into practical schemes for human welfare – into schemes for agricultural improvement, for industry, for better surgery and midwifery, for better laws.

There was to be no mystery. The ‘unknown’ signified only that which had not yet been understood: the Enlightenment recognised no category of ‘the unknowable’. And the most potent source of light to dispel the darkness of ignorance, blind authority, and religion, was science.

The men (and one or two women) of the Enlightenment formed what one of the foremost historians of the movement has called a self-consciously cosmopolitan, European ‘philosophic family’ (Gay, 1973, vol. 1, p. 6). Inevitably, though, branches of the family took tinges of colour from the various national cultures within which they grew.

This course is concerned with science in Scotland, one of the most dynamic centres of Enlightenment thinking. Writers speak of the mid-eighteenth century as Scotland's ‘Golden Age’. In order to get the flavour of this age, it is necessary to take a very broad view of what we mean by ‘science’. If we stay within the boundaries recognised by modern science faculties, we will miss most of what is distinctive about eighteenth-century Scotland. The interconnections and cross-fertilisation between disciplines that we now regard as having little to do with each other is one of the remarkable features of the Scottish scene. Geologists associated with historians, economists with chemists, philosophers with surgeons, lawyers with farmers, church ministers with architects.

Obviously, if we stretch the term ‘science’ too far, it disintegrates, but it is worth bearing in mind that the very term ‘scientist’ was not coined until the 1830s. Half a century earlier, a meeting of a learned society in Edinburgh, or Glasgow, or Aberdeen, would have brought together representatives of all the interests listed above, and they would all have recognised that they were engaged on a single project – namely, the pursuit of natural knowledge, by the light of observational, empirical methods, which in turn would lead to ‘improvement’ in the affairs of Scotland.

The Scottish conception of science and its purpose was neatly summed up in the programme of the Aberdeen Philosophical Society, or ‘Wise Club’ as it came to be known, founded in 1758: the Society aimed to investigate

> every Principle of Science which may be deduced by Just and Lawfull Induction from the Phaenomena either of the human Mind or of the material World; all Observations and Experiments that may furnish Materials for such Induction;

> the Examination of False Schemes of Philosophy and false Methods of Philosophising; the Subserviency of Philosophy to Arts, the Principles they borrow from it and the Means of carrying them out to their Perfection.
>
> (Chitnis, 1976, p. 200)

The summary is useful too in showing how the meaning of key words has shifted since the eighteenth century. As the name indicates, the members of the Aberdeen Society were interested in philosophy, but they used the term to signify what today would be regarded as science. The word ‘science’ in their quite typical usage meant simply ‘knowledge’. They were also interested in ‘arts’, by which they meant, not the fine arts, but skills or even trades: arts would have included activities like printing, or agriculture – it signified something close to the modern conception of technology. It is interesting to see that the practical Aberdeen Society stressed ‘the subserviency of Philosophy to Arts’, by which it meant that science provided a base for technology: science should ultimately, in their view, be in the service of technological application.

2 Origins of the Scottish Enlightenment

2.1 The Act of Union, 1707

Before examining Scottish science in detail, we need a sketch of the particular Scottish historical background from which an astonishing cluster of intellectuals and ideas emerged. It needs to be said at the outset, however, that there is no scholarly consensus as to why a small, poor country in Northern Europe should have made such a disproportionately large contribution to the thought of the age.

The event in Scottish history which tends to polarise opinion among scholars is the Act of Union with England, of 1707. The crowns of the two nations had been unified a century earlier, in 1603, when the Stuart James VI became king, not just of his native Scotland, but also of England, where he reigned as James I. But in 1707, Scotland gave up its parliament, and henceforth, the government of the country shifted from Edinburgh to Westminster. Some scholars have seen the Act of Union as precipitating a crisis in Scottish identity. Where, after 1707, might the intellectual energy of the nation be expressed?

The politically ambitious would speed to Westminster and join the scramble for office, shedding, in the process, their national loyalty. But what of those who remained in Scotland, yet who wished to contribute publicly to the nation's affairs? One route that might be predicted leads to the development and nourishing of a distinctive Scottish national culture, in protest against the loss of nationhood entailed by the Act of Union. After all, Scotland had its own languages – Gaelic in the Highlands, and Scots (a very markedly distinct form of English) in the Lowlands – and had its own unique culture and social system, especially in the Highlands. Perhaps we would predict the birth, after 1707, of a Scottish national, cultural movement.

This route was not taken. The leading lights of Scottish society came, almost wholly, from the Lowlands, and they directed their energies towards the establishment of an English-speaking, urban, civilised, commercial society that did not brandish Scottishness at every turn. Notably, they tended not to throw in their lot with the two Jacobite rebellions (of 1715 and 1745) which sought to restore the Stuart monarchy in Britain, and which embodied aspirations for Scottish national independence. The unwillingness of Scottish intellectuals to become identified with what they saw as a defeated, out-moded national culture is illustrated by one of the elegant deathbed utterances of perhaps the foremost intellectual of the age, the philosopher David Hume. He died, it was reported, ‘confessing not his sins, but his Scotticisms’: that is to say, he regretted not having succeeded in purging residual Scots phrases from his otherwise immaculate English prose.

For some scholars, then, the Act of Union had a ‘traumatic effect’. It left the Scottish elite bereft of real political institutions, yet dissatisfied with the remnants of an ancient Scottish culture. They engaged, it is argued, in a search for a new ‘cultural style’ (Phillipson, 1973, 1981).

For other scholars, the origins of the Scottish Enlightenment are to be found not in a sudden trauma, but buried within long traditions in the Scottish economy and society. Scotland was certainly a poor, small country in the late seventeenth century, it is acknowledged, but a number of writers have looked hard at seemingly moribund institutions and found that commercial, scientific and philosophical life was stirring. For these writers, the Scottish Enlightenment was the flowering of Scotland's own indigenous traditions. Three areas of enquiry have been fruitful: the Church, the universities and the economy.

2.2 The Church

The Scottish Church seems an unlikely place to look for the stirrings of enlightenment. In 1690, the General Assembly of the Church of Scotland passed an act against ‘the Atheistical Opinions of the Deists’, and, in 1696, an eighteen-year-old Edinburgh University student was executed for denying some of the propositions of Christianity. The legacy of the Scottish, Calvinist Reformation, it seems, was one of conformism, intolerance and narrow-mindedness.

But this is not the whole story. Another impulse from the Reformation itself was founded on the principle of critical scrutiny of Catholic tradition. This rational, critical impulse was felt by more liberal members of the Scottish Church, and was given typical expression by the Reverend William Wallace, a minister close to the pulse of Edinburgh University life. He preached, in 1729, that there must be a

> hearkening to the voice of sound reason, the examining impartially both sides of the question, with a disposition always to adhere to the stronger side and to embrace the truth wherever it appears in spite of all prejudices, of all opposition and authority of men. This is what I can never censure or apprehend being capable of being carried to an extreme,
>
> (quoted in Cameron, 1982, p. 123)

The tradition that Wallace represented grew steadily during the century, and the ‘Moderate Party’ of the General Assembly, as it became known, was receptive to – and in return made contributions to – Enlightenment thinking.

At a more general level, the intensely pious Calvinist tradition may have flowed in unexpected, worldly directions. Calvinist zeal may have been one of the ingredients in the development of Scottish industry and the economy in the eighteenth century. Here is how a leading Scottish historian puts it:

> The singleminded drive that is seen so often in business, farming and trade in the eighteenth century, and which appeared in cultural matters in men as diverse as Adam Smith, James Watt and Sir Walter Scott, is strangely reminiscent of the energy of the seventeenth-century elders in the kirk when they set about imposing discipline on the congregation. Calvinism thus seems to be released as a psychological force for secular change just at the moment when it is losing its power as a religion.
>
> (Smout, 1969, p. 92)

This is an attractive suggestion, but we should not underestimate the problems inherent in transmuting a religious drive into a secular one. Calvinism – indeed Christianity at large – teaches that human nature is depraved. In 1717, in criticising a Moderate minister, the Church Assembly held that he had attributed ‘too much to natural reason and corrupt nature’ (Cameron, 1982, p.119). Plainly, a number of radical intellectual moves had to be made before human nature could be presented (as it was in the Enlightenment) as notably uncorrupt – as fundamentally social, and likely to be virtuous, given a rationally organised society.

2.3 The universities

Turning to the universities, scholars have discovered that much more was going on during the late seventeenth century than the unimaginative training of young men for ministry in a dour church. Another legacy from the Reformation in Scotland was a recognition of the need for education, and, by the beginning of the eighteenth century, five universities, in four cities, were well established. (England, a far larger country, had only two.) Research and specialist teaching was held back by a system known as ‘regenting’, whereby individual ‘regents’ taught every subject to undergraduates. Not until the eighteenth century could lecturers break out of this generalist teaching of often outdated material, and provide specialist courses.

Even so, the universities were not backwaters. The work of Shepherd, for example, has shown that Newton's work was finding its way onto the syllabuses of Scottish universities from the 1680s. She has also reconstructed syllabuses at Edinburgh which show that the work of Copernicus, Galileo and Boyle was being taught (Shepherd, 1982). And in a reconstruction of Hume's education at Edinburgh University in the 1720s, Barfoot has found evidence that he was alerted there to the latest developments in science (Barfoot, 1990).

Not all innovation came from beyond Scotland's borders, and that which did was just as likely to have come from the Netherlands as from England, especially in the field of medicine. There were powerful links between medicine in Leiden and in Edinburgh. There were also entirely local traditions in mathematics, chemistry and medicine.

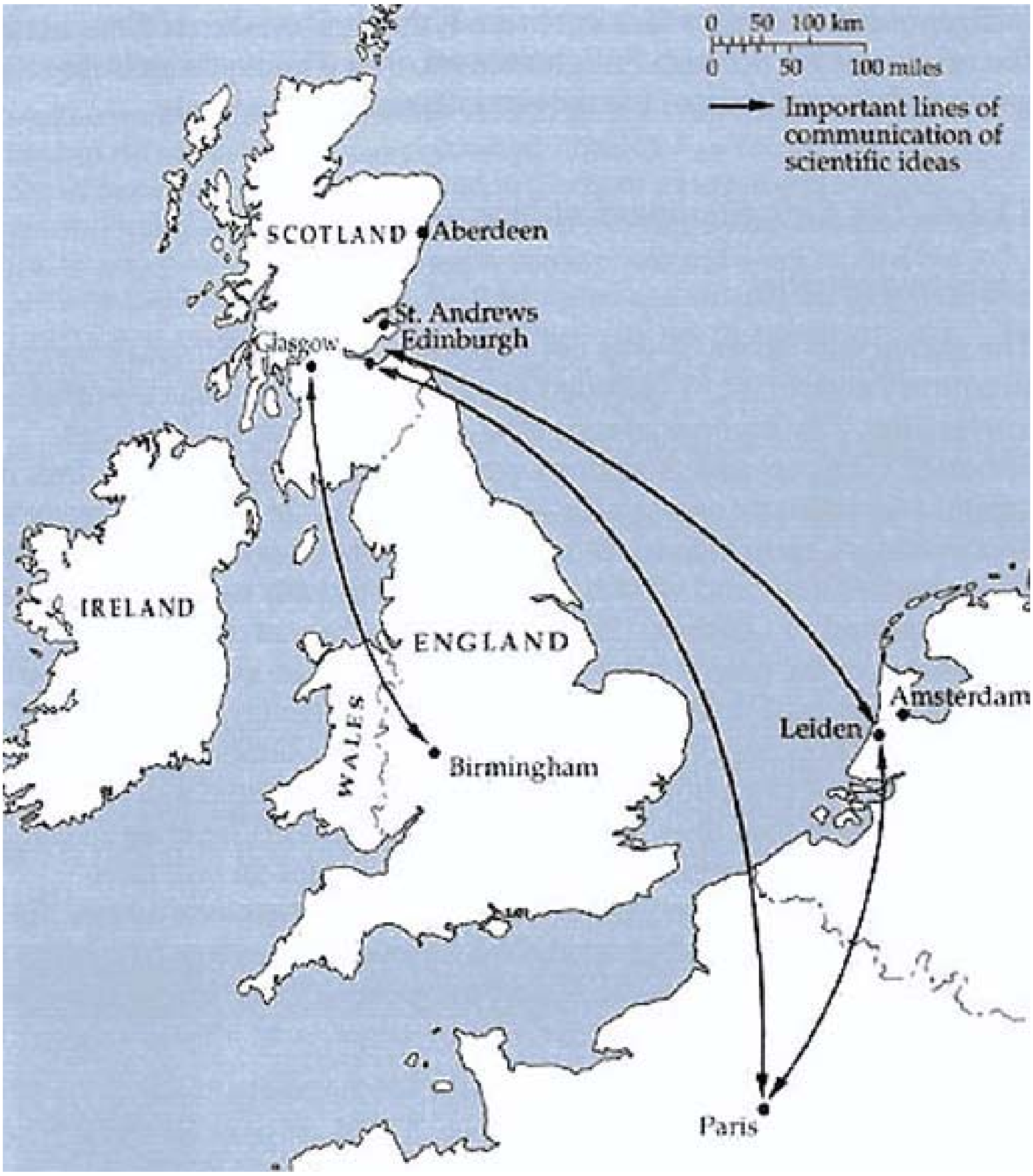

Figure 1: The Scottish connection

2.4 The economy

Turning lastly to the late seventeenth-century economy, a similar pattern of historical revision is revealed. Accounts stressing desperate poverty and backwardness have given way to accounts which indicate a more prosperous, vigorous state of affairs. In a survey of the Scottish merchant community, Devine has concluded that although the nation had not fully insulated itself against the calamity of bad harvests, its merchants were forward-looking and ready to innovate. They were not locked into conservative social hierarchies which inhibited commercial ventures. Sons of lairds became merchants: merchants bought land – it was an ‘open’ society. Here is Devine's conclusion:

> The business classes possessed the sophistication crucial to later advance. The merchant class made little intellectual contribution to the early Enlight-

> enment; their function was more indirect, to help to provide, with the professional and landed classes, a social and material environment which was not resistant to change, whether in the cultural or economic spheres.
>
> (Devine, 1982, p. 37)

It is from this background of mercantile openness that works like Adam Smith's *Wealth of Nations* (1776), the foundation text in the new social science of economics, came. From the same background, it is important to note, came the harsh industrial regimes of the early factories: enlightenment could sometimes be exploitation dressed up in new clothes.

No matter whether it is the supposed ‘trauma’ of the Act of Union, or longer, indigenous traditions which command historians' attention in their quest for the origins of the Scottish Enlightenment, there is no dispute about the general characteristics of the movement once it was underway.

3 The Enlightenment milieu

3.1 Clubs and societies

The milieu was urban. It was not a business of isolated individuals working in country estates, or of secluded academics, cloistered within unworldly universities. The scene was convivial, social. The focus was Edinburgh, although Glasgow and Aberdeen were active too. Cities were small. Even the capital was intimate enough for its intelligentsia to be able to meet regularly and casually. ‘Here I stand, at what is called the Cross of Edinburgh’, wrote an excited visitor, ‘and within a few minutes take fifty men of genius by the hand’ (quoted in Daiches, 1986, p. 1).

Perhaps the most characteristic expression of the conviviality and energy of the place was the club, or the society. Dozens of them were formed during the century, some short-lived dining and drinking clubs, some maturing into august scientific and medical bodies that still exist. Some, like the Poker Club (concerned with poking up sluggish intellectual fires, not card games), the Oyster Club or the Friday Club, at first sight seem frivolous – excuses, perhaps, for male claret-swilling – but behind the grandiloquence, serious issues were debated. The Oyster Club, for example, had among its founders the economist Adam Smith, the chemist Joseph Black and the geologist James Hutton – all pioneers in their fields and indebted to each other's criticism, help and stimulus.

Two societies can be singled out as being of fundamental importance in the discussion and dissemination of science. In 1731, the professors of medicine at Edinburgh founded the Medical Society of Edinburgh. The driving force was Alexander Monro, the first in a dynasty of three generations of Alexander Monros (known as *primus*, *secundus* and *tertius* – first, second and third) who dominated Edinburgh medicine. The Society published medical research and soon established for itself a reputation in European medicine.

When Alexander Monro *primus* fell ill, Colin McLaurin, an Edinburgh University mathematician and Newtonian, broadened the Society's scope to include all ‘philosophical’ topics (in the eighteenth-century sense), and the name changed to the Philosophical Society. The membership is a rollcall of the Scottish Enlightenment: McLaurin himself, Joseph Black, James Hutton, Adam Smith, David Hume, the chemist and doctor William Cullen, and the philosopher Dugald Stewart. The Society flourished from 1737 until 1783. Within its boundaries, smaller, special-interest groups, like the Newtonian Club, operated. The Society as a whole achieved the highest possible status when it was given a royal charter in 1783, to emerge as the Royal Society of Edinburgh, the premier scientific society of the country.

Medicine did not fall by the wayside when the Philosophical Society broadened its scope. A student medical society, which met first in 1734, grew, within forty years, into the Royal Medical Society, which was chartered in 1778. And along the way, it developed the full infrastructure of a lively scientific academy – premises, a library, a museum, a laboratory, prizes, publications.

The historian Roger Emerson, who has made extensive studies of Scottish science, has assembled a useful identikit picture of a member of an Edinburgh Society. It brings out clearly the social background and the wide-ranging commercial and intellectual interests of the men who founded the clubs and societies. Emerson's picture is of a typical member of the Philosophical Society, in 1739: such a member

> was an active professional man from the landed gentry who was politically involved and who held a patronage post which enhanced an income not wholly derived from rents. Tied to Edinburgh and to Scotland by economic interests, various responsibilities, language, sentiment, and perhaps by his training in Scots law, he was a place seeker whose prospects outside Scotland were limited but within the kingdom reasonably good. Well educated and usually the beneficiary of foreign travels, he was aware of the backwardness and provincialism of his country, and patriotic enough to wish to remedy it. Relying on provincial institutions for his status and income, he sought to raise both through improvements which would modernize the country, and allow it and him to play greater roles in the world. His enlightenment, and the work of his academy, would be practical, non-literary, career-furthering and conservative of his position as a member of an economic, social, and intellectual elite dominating the kingdom's institutions.
>
> (Emerson, 1979, p. 173)

3.2 Publishing

One of the strongest impulses in the Enlightenment was to codify knowledge and publish it widely. The most notable example of this impulse is the French *Encyclopedic*, 'a rational dictionary of the sciences, art and trades’, published chiefly in Paris in the 1750s and 1760s, under the indomitable editorship of Denis Diderot. The seventeen volumes of text and eleven volumes of plates were intended to summarise and clearly present everything that was worth knowing, from the construction of a water wheel or a glass manufactory to the latest theories in the psychology of perception.

The impulse which drove Diderot was working in Edinburgh too. A number of encyclopaedias were started, but the venture which became the most famous was the *Encyclopaedia Britannica*, which started in the 1760s. *Britannica* was coaxed into life by the printer, William Smellie, a man who, though without formal academic qualifications, was a key figure in the dissemination of the work produced within Edinburgh. By the turn of the century, and with perhaps significantly less bashfulness about its origin, the *Edinburgh Review* was launched. This journal quickly achieved a British reputation and became one of the most influential reviews of science, politics, economics and the arts.

Figure 2: An ideal of the Academy: the happy union of arts, science and technology. (Note that the title does not signal the encyclopaedia's Scottish origin – a further indication of the movement's ambivalent attitude to nationhood.)

(From frontispiece to the *Encyclopaedia Britannica*, 3rd edn, Edinburgh, 1788. Reproduced by permission of the British Library Board.)

British Library Board

3.3 Architecture

Printing and publishing, then, had their connections with the Enlightenment programme. Architecture too was related. The Adam family of architects (the father and his two sons) moved in the Edinburgh circle of the intellectuals. The young Robert Adam, for example, attended both McLaurin's mathematics lectures and Monro's anatomy lectures at the university, and his home life was enlivened by regular visits from the leading lights of the city. As one contemporary described the household, in a rolling eighteenth-century sentence:

> The numerous family of Mr Adam, the uninterrupted cordiality in which they lived, their conciliatory manners and the various accomplishments in which they severally made proh'cience, formed a most attractive society and failed not to draw around them a set of men whose learning and genius have since done honour to that country which gave them birth …
>
> (quoted in Fleming, 1962, p. 5)

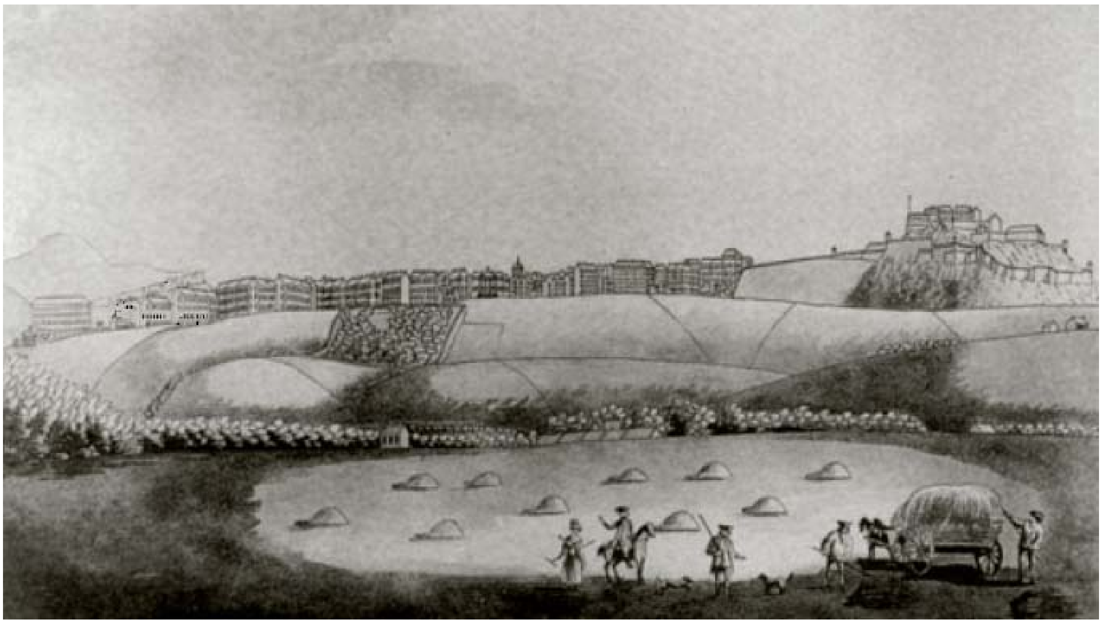

Figure 3: North view of the new and old towns of Edinburgh, from Inverleith, 1781

(By courtesy of the Edinburgh City Libraries.)

Edinburgh City Libraries

In the mid-century, Edinburgh was still an ancient city clustering around the castle and stretching down the hill to the neglected royal palace of Holyrood. But in 1752, the astute provost of the city, George Drummond, launched a plan to lay out a new town, beyond the North Loch, which would itself be drained. There were setbacks, but steadily there arose a rational grid of coolly elegant streets and squares, relieved by the occasional curve or gradient.

As it arose, however, the New Town, as it became known, was failing quite to realise the grandeur implicit in the ground plan, and in 1791, Robert Adam, who was by then making his fortune in England, was called in to design a monumental square in order to demonstrate just what could be done with urban housing, if conceived on a grand scale. The result is Charlotte Square, in which rows of terraced houses, built for the prosperous bourgeoisie, are successfully subordinated to a conception of a single, palatial edifice.

It would be too slick to present the elegant, rational Edinburgh New Town simply and baldly as the embodiment of Scottish Enlightenment – especially as the leading lights of the movement preferred to stay over in the racier old town – but in tracing the networks of people and ideas that flourished in the city, the route that leads to architecture and town planning is not to be ignored.

3.4 The role of the Edinburgh Town Council

This route incidentally leads us to another important feature of the movement, namely the role of the Edinburgh Town Council and its provosts. (The English equivalent would be a lord mayor.) Throughout the eighteenth century, the Town Council, with a policy of enlightened self-interest, promoted the city by sponsoring or patronising its academic, medical and scientific life. The Council regarded the city's university, infirmary and medical school as institutions which, if given enough prestige, would not only stop the drift of Scottish students and their fees to foreign universities – especially to Leiden for medical training – but also reverse the flow and attract fee-paying students to Edinburgh from across Europe and America. Accordingly, it took an active role in the appointment of professors who would bring fame. As early as 1713, the Council minuted its reasons for appointing James Crawford to the chair of chemistry at the university: the appointment was made

> … particularly considering that through the want of professors of physick and chymistry in this Kingdome the youth who have applyed themselves to study have been necessitat to travel and remain abroad a considerable time for their education to the great prejudice of the nation by the necessary charges occasioned thereby …
>
> (quoted in Christie, 1974, pp. 127–8)

Another such appointment was that of Colin McLaurin, the mathematician and Newtonian, to the chair of mathematics in 1725. McLaurin had formerly been at Marischal College, Aberdeen, where he had taken a rather high-handed view of his teaching duties. Somewhat oddly, this did not count against him when he was recruited for Edinburgh. What counted for him was a growing European reputation: a rising star could be caught. The tempting modern analogy is with those town councils who invest in their cities' football teams. The perhaps more sober conclusion of the historian who has investigated this episode is that McLaurin's appointment guaranteed that ‘the University of Edinburgh became an acknowledged centre for the diffusion of Newtonian mathematics, astronomy, and natural philosophy by the most gifted and accomplished British disciple of his generation’ (Morrell, 1974, p. 86).

McLaurin also mended his lackadaisical attitude to lecturing, and taught courses which included surveying and gunnery: his classes were not just for aspiring young mathematicians; they were also to serve the practical needs of students who intended to become engineers and army officers (Christie, 1974, p. 125). The architect Robert Adam, it will be recalled, also attended McLaurin's classes.

Regenting (the system of low-grade generalist teaching) came to an end in Scottish universities in the early decades of the eighteenth century, opening the way to the endowment of specialist professorships. In Edinburgh, for example, there were already chairs in natural philosophy, medicine and mathematics, surviving from the seventeenth century, but to these were added chairs in botany, anatomy, midwifery, chemistry, *materia medica* (the study of the materials, chiefly botanical, from which medicines were prepared), surgery, astronomy, agriculture. The patronage shown by the Town Council paid off: students did come, from home and abroad, and the number of graduates steadily rose.

The Town Council's investment in university teaching was shrewdly limited. Professors' salaries were not large. It was intended that the basic salary should be enhanced by a system that strikes terror into the heart of the twentieth-century academic: most of the income of eighteenth-century academics came from class fees paid by students. The stark and salutory implication was that poor lectures, attracting small numbers of students, would generate only a dismal income. Adam Smith, a successful professor at Glasgow University, and advocate of the market economy, recognised the compelling logic of the system:

> It is the interest of every man to live as much at his ease as he can; and if his emoluments are to be precisely the same, whether he does or does not perform some very laborious duty, it is certainly his interest … either to neglect it altogether, or, if he is subject to some authority which will not suffer him to do this, to perform it in as careless and slovenly a manner as that authority will permit …
>
> (quoted in Chitnis, 1976, p. 140)

Chitnis has compiled figures to show that class fees contributed much more to professors' salaries than did their basic salary. At the end of the century, for example, the professor of anatomy boosted a basic salary of fifty pounds to nearly a thousand (p. 152).

In sum, then, the milieu of the Scottish Enlightenment was its university cities, where flourished groups of characteristically clubbable intellectuals, divided by no ideological rifts, all committed to the pursuit of natural knowledge, in the general context of a commitment to the improvement of Scotland's, and their own, fortunes. They were supported by civic authorities, by an enterprising commercial culture, by extensive international scholarly contact, and even by the moderate wing of the Church.

Within this milieu, a scientific and medical community had, by the middle of the century, reached maturity – a maturity which meant that it was independent of the accidental incidence of a handful of energetic individuals. By 1760 it had built itself an infrastructure of learned societies, journals, specialist university teaching and research, and last, but not least, connections with agriculture and industry. The scientific and medical community could reproduce itself: it wouldn't collapse at the death of one particular and influential member (Christie, 1974).

4 The leading figures of the Scottish Enlightenment

At this point, before we move on to look in greater detail at the work of a couple of characteristic and influential Scottish scientists, it will be useful to stand back and take a survey of the leading members of the scientific and medical community.

One of its most eminent members, Adam Smith, pioneered the discipline of economics, which is not customarily included within science today. But to exclude him from our survey would be to misrepresent the unfenced, boundary-free territory across which eighteenth-century intellectuals ranged. Smith was professor of moral philosophy at Glasgow University and associated regularly with the leading lights of the European philosophic community. He published the famous *Wealth of Nations* in 1776. Smith's concerns, however, were by no means purely economic. Along with less-well-remembered scholars, he was engaged in one of the fundamental enquiries of the Scottish movement as a whole, namely the enquiry into the nature of humankind and human society.

In the field of medicine, the Monro dynasty commands attention. Alexander Monro *primus*, trained at Leiden, was appointed by the Town Council in 1720 to be professor of anatomy. His grandson, Alexander Monro *tertius*, held the post in the 1840s, by which time Edinburgh medicine had developed the full range of institutions – university lectures, a teaching hospital, learned journals and societies.

It should not be too readily assumed, however, that prestigious and well-supported medical institutions invariably led to improvements in patients' health. Historians of medicine have yet to resolve the question of whether eighteenth-century hospitals enhanced patient's chances of recovery or were, rather, ‘gateways to death’ caused chiefly by infections. The effectiveness of the most brilliant surgical skills – in amputating limbs, or removing urinary stones, for instance – was considerably diminished by shock and post-operative infections. Nor should it be assumed that medicine was solely a metropolitan affair, conducted by a handful of well-to-do physicians, surgeons and their students. Medical handbooks found their way into the households of citizens of moderate means.

The most famous of these handbooks is William Buchan's *Domestic Medicine*, published in 1769 and running to 22 editions by 1822. Buchan was an Edinburgh-trained doctor, and his book embodied the rational, common-sense principles of the Enlightenment. In the absence of antibiotics, medicine was incapable of making spectacular breakthroughs in healing the sick, but books like Buchan's – with its sober calls for moderate living, for publicly-funded inoculation schemes, for an end to superstitious practices in child-birth and child-rearing (he recommended, for example, that fathers should play an active part in rearing their children and ‘ought to assist in every thing that respects either the improvement of the body or the mind’ (1769, p. 7)) – did introduce the new medical thinking into the life of the community and led to modest improvements in its health.

Medicine was linked with the physical sciences, notably in the person of William Cullen, who lectured on medicine at Glasgow University before moving to Edinburgh in 1756. There, he combined research and teaching in both medicine and chemistry. He taught on the wards of the new Edinburgh Infirmary, was president of the Edinburgh College of Physicians, as well as holding the chair of chemistry at the university. He was a popular, pivotal figure in Scottish science and had a great influence on the young chemist Joseph Black (see Section 3).

5 James Hutton

5.1 Early career

James Hutton (1726–97) conforms fairly closely to Emerson's identikit picture of an intellectual of the Scottish Enlightenment. His chief scientific work was his *Theory of the Earth*, which was launched at meetings of the Royal Society of Edinburgh in 1785 and eventually expanded and published in two large volumes, ten years later, in 1795.

Figure 4: James Hutton (1726–97)

(Scottish National Portrait Gallery)

Scottish National Portrait Gallery

He was the son of a well-to-do Edinburgh merchant and was educated first at the city's university, where, like many students, he was particularly interested in chemistry. From Edinburgh University he took what was the natural route for young men who were keen to extend their studies in science: he went to Paris, and from there to the university which features again and again in the background to the Scottish Enlightenment – Leiden, in the Netherlands. The presiding spirit at Leiden was that of the doctor and chemist Hermann Boerhaave (1668–1738). Boerhaave's ideas influenced a generation of students, including those who returned to Scotland to establish the Edinburgh Medical School in 1726. Although Hutton graduated as a doctor at Leiden in 1749, he never practised regularly.

Instead, he returned to Edinburgh and set up a profitable chemical works which produced sal ammoniac (ammonium chloride) – a substance used as a flux in the metalworking trades and in the textile industry. Typically, Hutton was not averse to dirtying his hands, either with chemicals or with trade. Equally typically, he did not rest content as a successful chemicals manufacturer, but moved on into agriculture when he inherited two farms. He studied the latest agricultural techniques with a view to introducing them on his farms.

Farming, like the chemical industry, was unable to sustain his interest, and he moved on to geology. In making this move, though, he was able to take with him much of the knowledge he had derived from his earlier enterprises. Farming had prompted his interest in the structure of the earth's crust. Drainage schemes and quarrying opened sections through earth and rock which intrigued him, and in pursuit of his twin interests in agricultural improvement and the structure of the landscape, he travelled extensively around Scotland.

Eventually, in 1767, Hutton returned to Edinburgh, where he slotted comfortably into the Enlightenment milieu. He associated with Adam Smith, Joseph Black, the historian William Robertson, the anthropologist Lord Monboddo and the engineer James Watt. Through Watt, he met the members of the Lunar Society of Birmingham, a group of scientists, engineers and industrialists from the English Midlands. In short, Hutton was closely in touch with activities in a host of related and vigorous areas of enquiry.

5.2 Background to *Theory of the Earth*

The two volumes of *Theory of the Earth* embody a startlingly original conception of the processes which shape the earth's surface, and they contain some vivid observations, drawn from Hutton's travels. However, they are poorly organised, repetitive and sometimes obscure. In a most helpful survey of Hutton's work, from which this section draws liberally, Jean Jones quotes from a wonderfully direct letter that a saddlesore Hutton wrote while on a field-trip in Wales: ‘Lord pity the arse that's clagged to a head that will hunt stones’ (Jones, 1986b, p. 127). Such admirable conciseness is absent from the *Theory*, but the two volumes are a foundation text in the science of geology, and are well worth exploring.

This brief account of his life stresses the practical and commercial aspects of Hutton's life. However, another influence is at work in his geological theorising: the book is very far from a handbook for coal prospectors. It is a grand attempt, as its title indicates, to establish the principles which govern the structure and shape of the earth's crust. Given the materials with which Hutton worked – rivers, rocks, volcanoes, oceans, fossils – it is plain that he could never formulate neat mathematical laws to account for landforms, but the drive of his theorising is always to describe geological processes in terms of the interplay of two contending natural forces: elevation and erosion.

It is equally plain that Hutton's work was inspired and regulated by his deistic religious beliefs. Deists put aside the Christian Revelation, with its scripture, miracles and incarnation, in favour of an unimpassioned belief in a Divine Architect whose sole purpose was to set the universe running. In so doing, deists who happened also to be geologists put aside the account in the book of Genesis of the formation and history of the world. Christians, on the other hand, were gripped by the powerful story of the seven days of Creation, of God's subsequent anger and the Flood. Not until the nineteenth century, and for some Christians not even then, did non-literal readings of the biblical Creation story start to make headway.

Hutton's deism enabled him to sidestep all problems of harmonising his theory with scripture. One of the remarkable features of the *Theory of the Earth* is the absence of references to the account of Creation which had possessed the European imagination for nigh on two thousand years: the Genesis story seems to have faded almost clean away in the blaze of the Enlightenment. Hutton made only oblique, but entirely civil, references to the biblical account. Here, for example, is how he handles the idea of the Flood:

> Philosophers observing an apparent disorder and confusion in the solid parts of this globe, have been led to conclude, that there formerly existed a more regular and uniform state, in the constitution of this earth; that there had happened some destructive change; and that the original structure of the earth had been broken and disturbed by some violent operation, whether natural, or from a supernatural cause.

He goes on to say that his own theory gives a perfectly satisfactory account of the phenomena supposedly resulting from a great cataclysm, and concludes:

> Therefore, there is no occasion for having recourse to any unnatural supposition of evil, to any destructive accident in nature, or to the agency of any preternatural [i.e. supernatural] cause, in explaining that which actually appears.
>
> (Hutton, [1795] 1959, vol. 1, pp. 165–6)

This is not to say that religious belief played no part in his theorising. On the contrary, it was a powerful stimulus. Hutton's fundamental belief was that the earth has been formed for a purpose. That purpose is the support of life, and especially human life. Furthermore, in Hutton's view, the discovery of the way in which this purpose has been achieved leads enquirers to a noble conception of the Divine Architect.

Hutton's belief in a wise providential ordering of a world which, no matter how it changes, is always bountifully equipped to support life is not just a polite decoration to his work. It actively regulates his theorising. This *teleological* view, stressing the purposeful drive towards an end, leads Hutton to assume, for example, that no matter how radically the face of the earth has been remodelled during geological time there has always been a harmonious relationship between land-mass and ocean: he could not conceive of the possibility of there ever having been a time when life on land was impossible. ‘It is only required’, he wrote, ‘that at all times, there should be a just proportion of land and water upon the surface of the globe, for the purpose of a habitable world’ (Hutton, [1795] 1959, vol. 1, p. 196).

The purpose of a ‘habitable world’ is Hutton's answer to the teleological question ‘What is the earth *for*?’. Moreover, in characteristically Enlightenment fashion, Hutton declares further that life is essentially happy:

> It is of importance to the happiness of man, to find consummate wisdom in the constitution of this earth, by which things are so contrived that nothing is wanting, in the bountiful provision of nature, for the pleasure and propagation of created beings; more particularly of those [i.e. humans] who live in order to know their happiness, and know their happiness on purpose to see the bountiful source from whence it flows.
>
> (Hutton, [1795] 1959, vol. 2, p. 183)

Such cheerful sentiments are a long way from the Christian tradition, strong in Scottish Calvinism, which asserted humanity's sinfulness.

5.3 Hutton's geology: *‘No vestige of a beginning – no prospect of an end’*

Geologists are engaged on the business of reconstructing the earth's past and determining the agents of geological change. The only documentary evidence of the earth's origins and ancient past, and of the agents that had caused change, available to Hutton was the book of Genesis, and he had sceptically put it aside, along with miracles. But what if the processes that are *presently* observable were to be taken as the key to the past? How far might geological enquiry go with the assumption that what is now going on is all that has ever gone on – that the modern world presents an exhaustive catalogue of the processes that have shaped the world, and are continuing to shape it?

Hutton's originality lies in his readiness to go all the way with this assumption. He produced a theory which pictured an earth in which ‘the purpose of a habitable world’ has perpetually been achieved by a set of perfectly balanced agents of natural destruction and renewal. Earth history has no direction: it is now, and always has and will be, in a steady-state. The challenge to the geologist is to show how the steady-state is maintained – to make a survey of the agencies of destruction and renewal at work in the landscape.

What were Hutton's agents of destruction and renewal? Briefly, he argued that rocks are formed at the bottom of the sea and are composed, first, of material eroded from the neighbouring landmasses. Continents are inexorably being eroded away, and their fragments are washed down rivers to the sea. Secondly, rocks are composed of the remains of sea-dwelling animals: calcareous rocks – limestones, chalk, marble – simply *are* the consolidated remains of countless populations of shellfish whose shells have sunk to the sea-bed. All this material, either from former continents or from former living things, consolidates on the sea-bed where, under pressure from the sea, it is baked by the subterranean heat of the globe (a heat which, in Hutton's view can be reliably inferred from the action of volcanoes). As ancient continents are relentlessly ground away, subterranean heat slowly upheaves sea-beds elsewhere and new continents are born. Nothing is permanent: all is in a flux of destruction and renewal.

In Hutton's account, geological time is directionless – it's not going anywhere: the earth has proceeded from no primeval state, and it will not culminate at some future final point. The steady-state of a habitable world can be projected backwards into the eternal vistas of the past, and can confidently be predicted, stretching into the equally endless vistas of the future. ‘Time’, he wrote, ‘is to nature endless and as nothing’ (Hutton, [1795] 1959, vol. 1, p. 15). And in one of the most memorable utterances in the history of geology – one in which Hutton exhibited an uncharacteristic eloquence – he concluded that his researches have shown that the present landscape is built from the materials of former landscapes, which in turn are built from yet earlier landscapes, which in turn stretch back in endless succession. Sounding the standard, eighteenth-century Newtonian note, Hutton wrote:

> For having, in the natural history of this earth, seen a succession of worlds, we may conclude that there is a system in nature; in like manner as, from seeing revolutions of the planets, it is concluded, that there is a system by which they are intended to continue those revolutions. But if the succession of worlds is established in the system of nature, it is in vain to look for anything higher in the origin of the earth. The result, therefore, of this physical enquiry is, that we find no vestige of a beginning, – no prospect of an end.
>
> (Hutton, [1795] 1959, vol. 1, p. 200)

How could Hutton be so confident that he could find ‘no vestige of a beginning’? Other geologists had affirmed that rock strata could be sorted into a single sequence, stretching from ‘primitive’ rocks, formed when the world was young, up to modern rocks. Knowledge of the fossils (remains of living things) which characterise each rock formation was sketchy, but it seemed clear that there were rocks, low down in the sequence, which contained no fossils at all. It seemed reasonable, therefore, to say that the earth has developed uniquely, from a primitive, lifeless condition up to the present. Hutton challenged this by saying that there was, in effect, no such thing as a primitive rock. All rocks, no matter how low in the sequence, no matter how contorted, were formed, he argued, from the sorts of material that are still abundant in the world, and by the processes that are still observably at work in the landscape. If no fossils can be found in them, it is because they have been obliterated by the pressure and the heat which produced the strata.

Hutton's prosaic writing rarely does justice to the huge imaginative leap he made in grasping the explanatory potential of small, mundane modifications to the landscape – like the rolling of rocks downstream by rivers, or the accumulation of seashells on the sea-bed – when these modifications are given indefinite time in which to accumulate. It was remarkable to have been able to contemplate a mountainous country like Scotland, built seemingly of durable and stable rock, as, on one hand, having been built from strata laid down aeons ago beneath now vanished oceans, and, on the other, as potential raw material from which, in the immeasurably distant future, a new continent would be formed.

5.4 Hutton's geology: The Jedburgh unconformity

One concrete example from the *Theory of the Earth* will perhaps indicate the way in which Hutton could read features of the landscape as evidence of the action of forces acting over immeasurably long periods. He had been geologising in the valley of Jed Water, near Jedburgh, in the Borders area between England and Scotland. From his observations in the neighbouring Teviot valley, he expected the Jed to be running over a bed of horizontally laid, soft strata which were sometimes exposed as sections alongside the river. However, in his own words:

> I was surprised with the appearance of *vertical* strata in the bed of the river, where I was certain that the banks were composed of horizontal strata. I was soon satisfied with regard to this phenomenon, and rejoiced at my good fortune in stumbling upon an object so interesting to the natural history of the earth, and which I had been long looking for in vain.
>
> … above those vertical strata, are placed the horizontal beds, which extend along the whole country.
>
> (Hutton, [1795] 1959, vol. 1, p. 432, my italics)

What Hutton had found was what is now known as an ‘unconformity’: a junction between sets of rocks of quite different types, formed at quite different epochs. The Jedburgh unconformity was sketched by Hutton's travelling colleague, John Clerk, and appeared as a delightful engraving in the *Theory of the Earth* (see Figure 5).

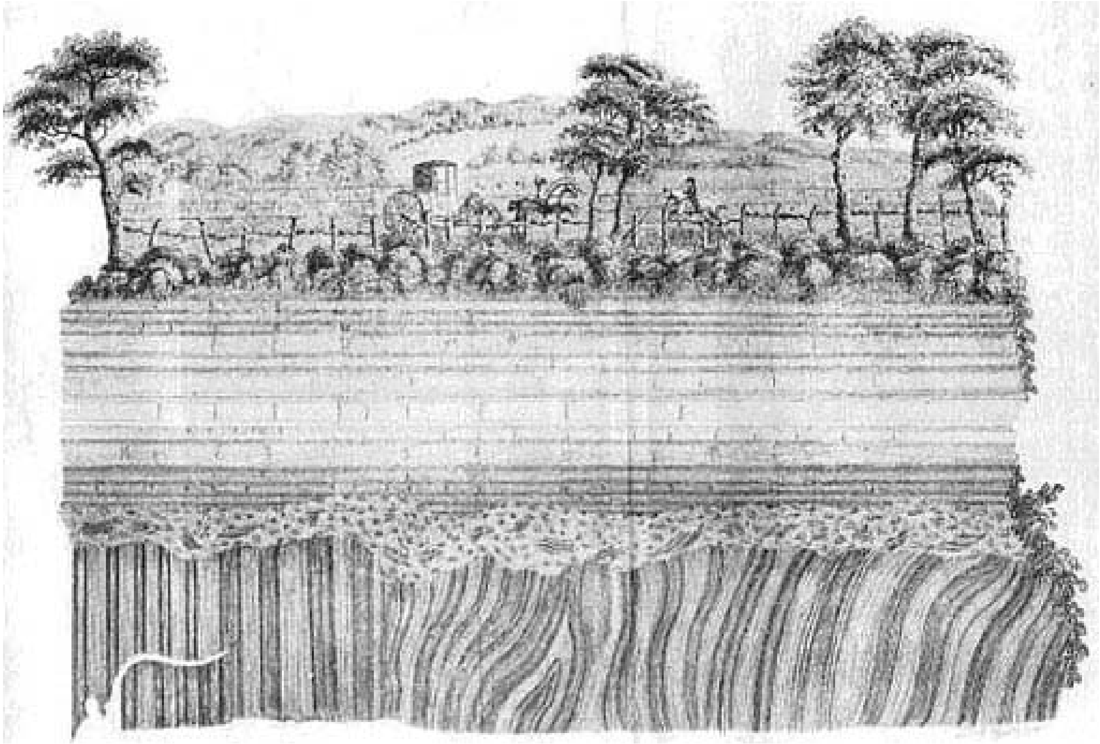

Figure 5: Unconformity near Jedburgh (From Hutton, *Theory of the Earth*, vol. 1, Edinburgh, 1795, plate 3.)

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British Library Board

How was the unconformity to be explained? Hutton proceeds, in the *Theory of the Earth*, by eliminating what he considers to be unsatisfactory explanations. For example, it is difficult to imagine that the upper, horizontal strata could have been laid down *before* the vertical strata beneath them: this would entail the subterranean building of vertical strata which somehow were ‘cut off abruptly’, in a straight edge, at the level where they met the overlying horizontal strata. Hutton rejects a number of other possibilities and then advances his own explanation. The strata which are now vertical were, like nearly all rocks, laid down horizontally, beneath the sea. As they were upheaved to form land, they were twisted into the vertical. Then

> by the effects of either rivers, winds, or tides, the surface of the vertical strata had been washed bare; and … this surface had been afterwards sunk [beneath the sea] below the influence of these destructive operations, and thus placed in a situation proper for the opposite effect, the accumulation of matter prepared and put in motion by the destroying causes.
>
> (Hutton, [1795] 1959, vol. 1, p. 435)

That is to say, the upheaved vertical strata had been planed down by erosion, and had sunk again to the bottom of the ocean to become the bed upon which a new set of horizontal strata began to accumulate. Hutton fortifies this suggestion by pointing to the layer of boulders and stones that occur at the intersection of the two sets of strata: they are, he claims, fragments of the lower, vertical series, which became detached during the long period of erosion.

Now, this may all look a bit confusing to a reader unfamiliar with geology, or commonplace to a reader who knows the basics of the science, but it is worth spelling it out, in order to show the confidence with which Hutton could, with perfect equanimity, contemplate the building and erosion of huge landmasses.

In the case of Jedburgh, he postulated the following sequence. There was once an ocean, where Jedburgh now stands, in which collected both the detritus of the neighbouring landmass and the detritus of tiny marine organisms. Horizontal beds of rock, composed of this detritus, were consolidated at the bottom of the ocean. Then, there was a period of upheaval which twisted and raised these beds vertically above the sea, where they were exposed to weathering and erosion for sufficient time for them to be planed down to a level.

A period of subsidence followed, during which the rocks sank below the ocean again. A new sequence of horizontal sedimentary rocks consolidated on the base of the old, subsiding rocks. Lastly, the whole mass was upheaved yet again. Finally, the unconformity revealed itself to Hutton in the spectacular section cut by the humble river Jed. ‘Finally’, though is the wrong word to use, for Hutton said that there is ‘no prospect of an end’, the forces that wrought these titanic changes are still at work and will eventually drastically remodel the Borders landscape.

It took the best part of a century for Hutton's vision, transmitted through later geologists, to be sanctified, as it were, by the elite English culture and embodied famously in the verse of the English Poet Laureate Tennyson in the most widely read poem of the nineteenth century:

There rolls the deep where grew the tree.
O earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of the central sea.
The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.

(In Memoriam, 1850, section 123, lines 1–8)

6 Joseph Black

6.1 A lifelong academic

Hutton can in many ways stand as a representative of the intellectuals of the Scottish Enlightenment. But they were not entirely homogeneous in their intellectual and religious outlooks. The chemist Joseph Black (1728–99) was a close friend of James Hutton (and Adam Smith), but the two men were quite different. Whereas Hutton was robust and disorganised, Black was pallid and precise. Hutton operated outside the universities, but Black was a lifelong academic. If Hutton gained his interest in geology from his industrial and farming activities, Black came to chemistry from his medical studies. Whereas Hutton was keen to speculate about the origins of the earth, even calling his book *Theory of the Earth*, Black insisted that it was only the facts that counted, and deplored all speculation and theorising. Similarly, Hutton (like Black's colleague Cullen) made no secret of his deism, but Black's religious views remain an enigma even today and they played no part in his scientific work.

Figure 6: James Hutton (1726–97) and Joseph Black (1729–99) (From J. Kay, *A Descriptive Catalogue of Original Portraits*, Edinburgh, 1836)

(Photo: National Library of Scotland.)

National Library of Scotland

It would therefore be rash to assume that a case-study of a single figure, even one as illustrious as Hutton, can provide us with a complete picture of Scottish science in the eighteenth century. What light does Black's scientific activities shed on the Scottish

Enlightenment and what were his major contributions to the development of European science?

Joseph Black was born in April 1728, not in Scotland but in France, the son of an Ulsterman, who was a wine merchant in Bordeaux, and his Scottish wife. After four years' education in Belfast, Black went to Glasgow University at the age of sixteen. Pressed by his father to choose a profession after he completed his arts course in 1748, Black decided to take up medicine. Black was not particularly interested in becoming a physician, but the medical course enabled him to continue the study of natural philosophy under the new lecturer in chemistry, William Cullen (1710–90). This was a crucial step in Black's career, for Cullen was one of the first teachers of chemistry in British medical school to base his course on the general principles of chemistry, rather than *materia medica*.

6.2 Early research in Edinburgh

6.2.1 Magnesia alba

After four years with Cullen in Glasgow, Black transferred to Edinburgh to complete his medical studies. He then needed to select a topic for his MD dissertation, one which would involve chemistry, be of topical interest, and also touch upon a medical question. He decided to study the nature of causticity, the corrosive character of alkaline substances, such as quicklime (calcium oxide). He wrote to his father in December 1752 that he had chosen this topic because of a controversy between two Edinburgh medical professors, Robert Whytt (1714–66) and Charles Alston (1683–1760), stemming from their attempts to use limewater (a solution of calcium hydroxide in water) as a chemical means of dissolving excruciating urinary stones (Donovan, 1975, p. 172).

Rather than become directly entangled in a dispute between two professors, Black chose another alkaline substance for his own investigations. This was magnesia alba (magnesium carbonate), which was of medical significance because it was taken (and is still widely used) for acidic indigestion and, to quote Black, ‘it mildly loosens the bowels’ (quoted by Donovan, 1975, p. 193). This was important in a period when overeating of the wrong things and drinking often caused indigestion and constipation. His thesis, *De humore acido a cibis orto et magnesia alba* (Of the acid humour produced by food and of magnesia alba), was printed in June 1754.

He did not achieve his original aim of producing a substitute for limewater by roasting magnesia and treating the product with water, because magnesium oxide, unlike quicklime, is totally insoluble in water. Nonetheless, Black carried out about thirty chemical experiments on magnesia and calcinated magnesia, which he called magnesia usta. The tentative and disappointing results of Black's thesis were transformed a year later in an essay he read to the Philosophical Society of Edinburgh entitled ‘Experiments on magnesia alba, quicklime, and other alcaline substances’, in which he extended his investigations to quicklime and potash.

6.2.2 Fixed air

It was well known that ‘air’ was given off by magnesia (or limestone) when treated with acids. Black sought to show that this ‘air’, which he called ‘fixed air’ (carbon dioxide), is also lost when magnesia is heated. Hampered by practical difficulties in his efforts to collect the fixed air liberated during the heating of magnesia, Black used a series of chemical reactions to prove his argument. He dissolved the magnesia usta in sulphuric acid to produce a solution of Epsom salt. This solution was treated with fixed alkali (potassium carbonate), which precipitated magnesia. This regenerated magnesia, after being washed and dried, had the weight and the properties of the original compound.

As very little 'air' was given off during this sequence, the fixed air in the fixed alkali must have ended up in the magnesia. Black confirmed this by treating magnesia with sulphuric acid and then measuring the weight lost during this reaction, which was equal to the weight loss during calcination.

Black also noted that quicklime does not absorb ordinary air, but only the small quantity of fixed air contained in it. This implied that there were at least two chemically distinct 'airs', and Black knew that fixed air extinguished a candle. However, he was not interested in the chemical behaviour of gases, and although he carried out experiments which revealed that birds were unable to breathe in fixed air, he did not make any further contributions to the pneumatic chemistry he had so ably helped to found.)

6.3 Heat research

Andrew Plummer (*c*. 1698–1756), the chemistry professor at Edinburgh, suffered a stroke in 1755, and the Town Council appointed Cullen as his conjoint professor without consulting the stricken Plummer. Black, who had covered for Plummer until Cullen arrived, was appointed to Cullen's position at the University of Glasgow. This move also marked a change in the direction of Black's research. He now began to investigate the nature of heat, a central topic in eighteenth-century chemistry.

It is important to realise that most chemists in this period regarded heat as a substance, if perhaps one without measurable weight, and the study of heat was therefore considered an appropriate field for chemists. Hermann Boerhaave devoted a long section to 'fire' in his famous *Elementa chemise* (1732). In his lectures, Cullen listed 'fire' as the second primary cause of chemical change, after the elective attraction (chemical affinity) – precisely the order of Black's research (Donovan, 1975, p. 131). Black doubtlessly believed that some form of chemical combination took place between heated materials, such as water, and heat. At the same time, however, he was even more reluctant to hypothesise than Cullen. His work on latent and specific heats was not based on any theoretical foundation, except for a belief that substances possessed a capacity to take up heat.

It is thus unwise to regard Black's research as constructing a *theory* of heat. Black simply sought to make clear the manner in which a given substance, most notably water, absorbed heat. This was in keeping with the Enlightenment philosophy that it was important to establish the causes of natural phenomena by examining the facts, without resorting to speculative assumptions or 'hypotheses'. As he later explained to his former assistant John Robison (1739–1805), he considered every hypothetical explanation as a mere waste of time and ingenuity' (in Robison, 1803, vol. 1, p. vii).

6.3.1 Latent heat

The origins of Black's interest in the phenomenon of melting have been the subject of some debate. John Robison remarked, in his edition of Black's lectures, that Black had been struck by the simple fact that snow does not melt instantly on a sunny winter's day nor does a sharp night-time frost cause ponds to form thick layers of ice immediately

(Robison, 1803, vol. 1, pp. xxxvi-xxxvii). It is now generally agreed, however, that Black's interest in heat arose from his study of the temperature changes which take place when salts dissolve in water. Some salts give out heat, while others produce cold, and these differences forced him to think about the more general question of aggregation and heat.

Several scholars, notably Henry Guerlac (1982, pp. 15–16), regard Black's reflections on the observation of supercooling by Daniel Fahrenheit (1686–1736) as the crucial factor. (Supercooling is the phenomenon whereby the temperature of undisturbed chilled water can fall below 32°F without freezing, but when the water is shaken, the thermometer rises to 32°F and remains there until all the water has frozen.) Arthur Donovan (1975, pp. 224–5) argues that Black would have perceived a link between the fixing of 'air' by quicklime and the fixing of heat (so that it is no longer registered by the thermometer) by ice.

However he came to the question of why ice does not melt immediately the temperature rises above freezing, Black's experimental programme is clear. If the temperature – as measured by a thermometer – does not change while the ice is melting, can we be sure that the thermometer bears any relationship to heat at all, and if the temperature does not change, how can we measure the *quantity* of heat taken up by the ice? Black was able to confirm that a mercury thermometer was a reasonably accurate record of heat changes when no change of state occurred, by mixing equal volumes of hot and cold water and assuming that the temperature of the mixture was the average of the initial temperatures.

But how could the heat entering the melting ice be measured with the thermometer? Fortunately, Black recalled an experiment that a Scottish physician George Martine (1702–41) had published in 1740. He had put two thin glasses, one containing water and the other mercury, in front of a fire; if the fire is a steady one, the quantity of heat entering each vessel should be the same. Black adapted the idea by measuring the rise in temperature of water in one glass, while ice was melting in another one.

He had to wait for the winter to arrive so he could obtain the necessary ice, and the key experiment was made in December 1761. One glass contained water that had been frozen using a snow and salt mixture and the other held water that had been chilled to 33° F; the room temperature was 47°F. After half an hour, the water temperature had risen to 40°F, but the ice took ten and a half hours to reach the same temperature. Black calculated that the extra heat required to melt the ice – its *latent heat* – was equal to the heat required to raise the temperature of the water by 140°F. The term 'latent heat' was devised by Black from the Latin *latet*, 'hidden' (Robison, 1803, vol. 1, pp. xxxvii).

He then carried out a different experiment, which he later described as an 'obvious method' (Black, 1803, vol. 1, p. 122). He made a small block of ice, which was placed in hot water. Within a few seconds, the ice had melted and the temperature of the water had fallen from 190°F to 53°F. The ice, the mixture of melted ice and water, and the empty glass were all weighed. With this information, Black recalculated the latent heat of ice and the result this time was 143°F. The average was therefore 141.5°F, or 330 KJ/Kg in the modem SI system, close to the currently accepted value of 336 KJ/Kg.

6.3.2 Heat of vaporisation

Black read a paper on these experiments to the Glasgow Literary Society in April 1762, and then turned to the investigation of vaporisation. For reasons he himself found difficult to explain, Black was initially reluctant to accept that there was a similar heat of vaporisation. This was in spite of the fact that he (and presumably many cooks) had observed that it takes far longer to boil off water than it takes to raise water to boiling point.

In October 1762, he devised a very simple experiment to measure the heat of vaporisation. He took a flat-bottomed tinplated pan and heated small quantities of water in it, using a steady furnace. Knowing the initial temperature of the water (50°F), the time it took to reach boiling point (four minutes) and the extra time it took to boil off (twenty minutes), he could calculate the heat of vaporisation. The quantity he obtained was 810°F. (This is equivalent to 1890 KJ/Kg, rather less than the modern value of 2268 KJ/Kg.)

Almost exactly two years later, Black and his student William Irvine carried out the reverse experiment, namely the determination of the heat liberated when steam is condensed to water. Once again, Black displayed his penchant for the simplest apparatus. He used an ordinary laboratory still fitted with a condenser filled with water (at 52°F). The quantity of water condensed was measured and found to be at 132°F. The temperature of the water in the condenser was at 123°F. From this data, Black and Irvine calculated that the latent heat of steam was at least 774°F. This was obviously too low, but it was close enough to the 810°F Black obtained for the conversion of water to steam to show that the two processes were probably equal and opposite.

Black's work on the heat of vaporisation provides us with an early example of the interaction between science and technology, because Black and Robison were close friends of James Watt (1736–1819), the pioneer of steam power. Watt was born in Greenock, but he trained as a scientific instrument-maker in London. On his return to Glasgow in 1757, he was appointed instrument-maker to the university, probably through his friendship with Professor Robert Dick, who may have introduced Watt to Black. Black and Watt entered a partnership with Alexander Wilson, later professor of astronomy, in November 1758.

6.3.3 Specific heats

Finally, we must consider Black's contribution to the discovery of specific heats, the fact that different substances take up heat at different rates. Two experiments on mercury and water had indicated the problem. Fahrenheit had found that mixing equal volumes of mercury and water produced a striking result. If the mercury was initially hotter than the water, the temperature of the mixture was less than the average, and the reverse was true if the water was originally hotter. Martine's experiment, which we have met in connection with the latent heat of ice, shed more light on this matter. When two glasses, one containing water and the other an equal volume of mercury, were placed in front of a steady fire, the temperature of the mercury rose twice as rapidly as the water.

Black was able to solve these riddles. Mercury clearly had a lower capacity for heat than water, and hence it heated up (and cooled down) more rapidly. As he never published his conclusions, we know very little about his thinking on this question, but he may have arrived at this solution because he regarded the absorption of heat as a chemical process, and hence a function of chemical composition, rather than density, or bulk (as Boerhaave had suggested).

6.4 The Edinburgh professorship

Whytt, the Edinburgh professor of medicine, died in 1766 and Cullen was chosen to succeed him, largely with the aim of freeing the chemistry chair for Black. Black's transfer to Edinburgh was well received, and he fulfilled these expectations by being an excellent and popular lecturer. However, the Edinburgh chair also marked the end of his active research. One looks in vain for any sequel to his research on magnesia or his work on heat. With hindsight, foreshadowings of this change can be seen in Black's Glasgow period. He refused to publish his work on heat, and it was only made public when an unauthorised version, based on his lectures, appeared in 1770. Furthermore, in his last years in Glasgow, most of the research work was done by his assistants, William Irvine and John Robison.

However, the reasons are not too hard to find. He did not draw a salary as a professor, but had to rely on his lecture fees, and hence the number of students attracted to his course. Black's stock-in-trade was the elegant (rather than spectacular) lecture demonstration. With over 120 lectures to prepare and deliver between November and May, it doubtlessly reduced Black's scope for research, given his indifferent health. Black had become increasingly worried about his health – he had a bad chest – and probably felt that he did not have to prove his talents in chemistry now he had achieved his ambition of an Edinburgh chair.

Furthermore, he was an active physician, and while his private practice was small, he was also a manager of the Royal Infirmary and eventually a ‘Physician to the King in Scotland’, in addition to his work on the sixth to eighth revisions of the *Edinburgh Pharmacopoeia*.

His medical work was overshadowed by his growing role as an adviser to industry. To quote Robert Anderson, a leading authority on Black:

> Black was consulted by a considerable number of industrialists on an extraordinary wide range of topics. In the surviving correspondence these include sugar refining, alkali production, bleaching, ceramic glazing, dyeing, brewing,metal corrosion, salt extraction, glass making, mineral composition, water analysis and vinegar manufacture. In addition his opinion was sought on agricultural matters. (Anderson, 1986, p. W7)

For instance, Black suggested that caustic potash (potassium hydroxide), prepared by the action of quicklime on potash, was a better bleach for linen than potash or sour milk. At first, the authorities were concerned that caustic potash would weaken the cloth, but the Irish Linen Board permitted its use in 1770.

Black never changed the structure of his lectures from his arrival in Edinburgh until his retirement 30 years later. While he updated individual items over the years, the unchanging structure became an obvious handicap in a period when chemistry was transformed. Clearly, the pressure on Black's time and his poor health partly explain the lack of any thorough revision, but it was also a reflection of Black's lack of interest in theoretical chemistry. He presented the phlogiston theory propagated by the English pneumatic chemists in his lectures without any great enthusiasm; their speculative conjectures were not to his taste. However, he was equally chary of the new chemistry from France, especially its systematic nomenclature.

The agent of change was Sir James Hall (1761–1832), a pupil of Black and James Hutton, who visited Paris in 1786. The earlier influence of an uncle and the heady experience of meeting Antoine Lavoisier (1743–94) converted Hall to the new chemistry. On his return to Scotland, he gave a paper to the Royal Society of Edinburgh on ‘M. Lavoisier's new theory of chemistry’ in the spring of 1788. Hutton defended the phlogiston theory in a later paper, but Black was characteristically silent. However, Lavoisier wrote to Black in September 1789 to inform him that he had been elected a foreign member of the French Academy of Sciences. It appears from a second letter from Lavoisier in July 1790 that Black had spoken guardedly in favour of Lavoisier's ideas. In a warm response to this second letter, Black declared his support for Lavoisier's chemistry, despite a few ‘difficultys’, and confirmed that he had begun to teach it in his lectures (text of letter in Donovan, 1979, p. 245).

Although Black was now in his sixties, his eloquence and his dexterity with apparatus could still command the admiration of Henry Brougham (later Baron Brougham) in 1796. This was the last course Black delivered, and he handed his lecturing duties over to his former student Thomas Charles Hope (1766–1844), who had been converted to Lavoisier's teachings by Sir James Hall in 1788. Black's health now began to fail altogether, and he died suddenly in 1799.

Black had built up the reputation of the teaching of chemistry at the University of Edinburgh, but it did not continue to prosper after his death. Part of the blame must be laid at the feet of his successor, Hope, who has been described as ‘dull, pompous and uninspiring’ (Anderson, 1986, p. 112). The Edinburgh tradition of teaching and lecture demonstrations to the exclusion of original research meant that it was unable to meet the challenge from the research-based German universities, most notably Giessen, in the 1840s.

Black's failure to prepare Edinburgh for the nineteenth century, and his personal failure to build on his initial achievements, can be traced to his indifferent health and his personality. Adam Smith once described his close friend as ‘cool and steady’ (Mossner and Ross, 1977, p. 207). Black was a cautious and fastidious man, with a desire for precision, who was not given to enthusiasm and rash actions, amongst which he appears to have numbered scientific publications. It is significant that his only important publication, ‘Experiments upon magnesia alba’, was a direct consequence of his MD thesis. This unfortunate mixture of indolence and coolness limited Black's contribution to the Chemical Revolution.

Black's work on latent heat laid the foundations for Lavoisier's theory of heat as a weightless chemical element, caloric. But Black was more than an intellectual bridge between Newton and Lavoisier. By treating heat as a measurable quantity, which could be transferred from one body to another, Black paved the way for the development of thermodynamics, the science of heat, in the nineteenth century.

7 Conclusion

We have studied James Hutton and Joseph Black separately, but they can be properly understood only if they are considered as part of the close-knit community of philosophers and scientists which also included Adam Smith, David Hume, William Cullen and Dugald Stewart. For nearly seventy years of the eighteenth century, this group produced an intellectual ferment which placed Scotland at the forefront of the European Enlightenment.

By the end of the eighteenth century, Scotland had a mature scientific community, producing work which fed into both the wider European scientific and medical networks, and into Scotland's own developing industrial economy. The members of this community shared a common belief in the importance of reason, the goodness of humankind, and the serenity of nature. Equally, they shared a zeal for the commercial and agricultural improvement of Scotland's and their own fortunes. They were pioneers in several fields, particularly medicine, chemistry, geology, philosophy and economics. The advances they made underpinned the Industrial Revolution and the American Revolution.

What was, at the beginning of the eighteenth century, a small, poor, politically and culturally disorientated country, had, towards the end of that century, achieved a commanding status as one of the European centres of Enlightenment thought and practice.

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References

Anderson, R.G.W. (1986) 'Joseph Black', in D. Daiches et al. (eds), *A Hotbed of Genius*, Edinburgh University Press.

Barfoot, M. (1990) ‘Hume and the culture of science’, in M.A. Stewart (ed.), *Studies in the Philosophy of the Scottish Enlightenment*, Oxford University Press.

Black, J. (1803) *Lectures on the Elements of Chemistry*, John Robison (ed.), 2 vols, London, Longman Rees and William Creech.

Buchan, W. (1769) *Domestic Medicine*, Edinburgh, Barf our, Auld and Smellie.

Cameron, J.K. (1982) ‘Theological controversy: a factor in the origins of the Scottish Enlightenment’, in R.H. Campbell, and A.S. Skinner (eds), *The Origin and Nature of the Scottish Enlightenment*, Edinburgh, Donald.

Chirnis, A. (1976) *The Scottish Enlightenment*, London, Croom Helm.

Christie, J. (1974) ‘The origins and development of the Scottish scientificcommunity’, *British Journal for the History of Science*, 12, pp. 122-41.

Daiches, D. (1986) ‘The Scottish Enlightenment’, in D. Daiches et al. (eds), *A Hotbed of Genius*, Edinburgh University Press.

Devine, T.M. (1982) ‘The Scottish merchant community, 1680-1740’, inR.H. Campbell and A.S. Skinner (eds), *The Origins and Nature of the Scottish Enlightenment*, Edinburgh, Donald.

Donovan, A.L. (1975) *Philosophical Chemistry in the Scottish Enlightenment*, Edinburgh University Press.

Emerson, R. (1979) ‘The Philosophical Society of Edinburgh, 1737-1747’,*British Journal for the History of Science*, 12, pp.154-91.

Reming, J. (1962) *Robert Adam and His Circle*, London, Murray.

Gay, P.(1973) *The Enlightenment: An Interpretation*, 2 vols, London, Wildwood House.

Guerlac, H. (1982) ‘Joseph Black's work on heat’, in A.D.C. Simpson (ed.), *Joseph Black, 1728-1799*, Edinburgh, Royal Scottish Museum.

Hutton, J. ([1795] 1959) *Theory of the Earth*, 2 vols, Codicote, Wheldon and Wesley.

Jones J. (1986) ‘James Hutton’, in D. Daiches et al. (eds), *A Hotbed of Genius*, Edinburgh University Press.

Morrell, J. (1974) ‘Reflections on the history of Scottish Science’, *History of Science*, 12, pp. 81-94.

Mossner, E.C. and Ross, I.S. (1977) *The Correspondence of Adam Smith*, Oxford, Clarendon Press.

Phillipson, N. (1973) ‘Towards a definition of the Scottish Enlightenment’, in P. Fritz and D. Williams (eds), *City and Society in the Eighteenth Century*, Toronto, Hakkert.

Phillipson, N. (1981) ‘The Scottish Enlightenment’, in R. Porter and M. Teich(eds), *The Enlightenment in National Context*, Cambridge University Press.

Robison, J. (1803) Introduction, in J. Black, *Lectures on the Elements of Chemistry*, ed. J. Robison, 2 vols, London, Longman Rees and William Creech.

Shepherd, C. (1982) ‘Newtonianism in the Scottish universities in the seventeenth century’, in R.H. Campbell and A.S. Skinner (eds), *The Origin and Nature of the Scottish Enlightenment*, Edinburgh, Donald.

Smout, T.C. (1969) *A History of the Scottish People*, Glasgow, Collins.

Further reading

Anderson, R.G.W. (1982) 'Joseph Black', an outline biography, in A.D.C. Simpson (ed.), *Joseph Black, 1728-1799, Edinburgh*, Royal Scottish Museum.

Daiches, D. et al. (eds) (1986) *A Hotbed of Genius*, Edinburgh University Press.

Doyle, W.P. (1982) 'Black, Hope and Lavoisier', in A.D.C. Simpson (ed.), *Joseph Black, 1728-1799*, Edinburgh, Royal Scottish Museum.

Guerlac, H. (1970) 'Black, Joseph', in the *Dictionary of Scientific Biography*, vol.2, New York, Scribner's.

Guerlac, H. (1957) 'Joseph Black and fixed air', *Isis*, 48, pp. 124-51, 433-56.

Acknowledgements

'Science in the Scottish Enlightenment' (by Michael Bartholomew and Peter Morris) is Chapter 11 in *The Rise of Scientific Europe 1500–1800* (eds David Goodman and Colin A Russell) © 1991, 2003 The Open University. This chapter has been adapted for OpenLearn.

The text *The Rise of Scientific Europe 1500–1800* forms part of OU course AS208 *The rise of scientific Europe*.

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