THE SCIENTIFIC REVOLUTION AND THE MACHINE*

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There are three creative ideas which, each in its turn, have been central to science. They are the idea of order, the idea of causes, and the idea of chance. I begin at what is perhaps the most fugitive of the three, the idea of order.

None of these ideas is peculiar to science, and the idea of order least of all. They have applications to science; but all three are of course older than these applications. All are wider and deeper than the techniques in which science expresses them. They are common sense ideas; by which I mean that they are generalizations which we all make from our daily lives, and which we go on using to help us run our lives.

Unhappily, common sense has no recorded history. We often suppose indeed that it has no development, and that what we call common sense today has always been common sense to everybody – which certainly is not true.

Science records all this more conveniently. Science has a history in which the growth of these ideas can be traced plainly. More than this, we can in that history detect the moments of surpassing interest, when the common sense ideas were being formed afresh. Such a moment is now plain in the history of the seventeenth century. That age, which made Newton and which Newton made, was a climax and a fresh beginning in English science. And I go directly to Newton himself because nothing so reveals that age as the remarkable character of its greatest man.

No man of science, no man of thought has ever equalled the reputation of Isaac Newton. No other man has made so deep a mark on his time and on our world unless he has been a man of action, a Cromwell or a Napoleon. Like Cromwell's and like Napoleon's, Newton's achievement was made possible by the coincidence, or better by the interplay of

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personality and opportunity. Each of these men, the man of thought as well as the men of action, entered history at a moment of social instability. Newton was born during Cromwell's revolution in the troubled 1640's; he was eighteen at the Restoration in 1660; and he published the *Principia* during the intrigues which ended by bringing William of Orange to England in the revolution of 1688. These are the moments when the powerful mind or the forceful character feels the ferment of the times, when his thoughts quicken, and when he can inject into the uncertainties of others the creative ideas which will strengthen them with purpose. At such a moment the man who can direct others, in thought or in action, can remake the world.

Newton was such a personality. That complicated and nevertheless direct mind, that imperturbable engine of thought has stamped its mark on everything he did. The stamp is Newton's style, and the style and the content are one; both are projections of the same single-minded personality.

Science is not an impersonal contruction. It is no less, and no more, personal than any other form of communicated thought. This paper is not less scientific because my manner is personal, and I make no apology for it. Science searches the common experience of people; and it is made by people, and it has their style. The style of a great man marks not only his own work, but through it the work of others for generations. The style of Newton's work as much as the content dominated science for two centuries, and in that time shaped its manner and its matter. But style is not the monopoly of the great, nor is its appreciation a vintage reserved for experts. The schoolboy who can tell a neat proof from a dull one knows the style, and takes pleasure in it. Indeed, he finds it easier to appreciate the style of science than the style of Shakespeare.

I cannot hope to transmit that style, its feeling and its detail, at this remove. It cannot be bought, canned and dehydrated, on pages ten and eleven of somebody's history of world knowledge, either in the chapters on science or on Shakespeare. We all understand that Shakespeare, the whole Shakespeare, cannot be got out of any book but his own collected works. So if we want the whole Newton, the man and the manner, the large nose and the strong thumb-print of his style, then we must read the *Principia* and the *Opticks*. Only in this way will we get the personality and the movement of the work, the massive ease and the fluent assurance which the *Opticks* shares strikingly with *Antony and Cleopatra*.

But we need not therefore come to a dead stop on aesthetics. After all few of us value the style so highly that we cannot bear to read Balzac and Stendahl in translation, and even Flaubert and Proust. Few of us certainly would learn French only in order to preserve this aesthetic Puritanism. And in the same way we must be content with science in translation. The science of an age, like its art or its music, has a style, yes. But it has a content and a structure too, larger than the work of any one man, within which the work of its men takes shape and meaning. Shakespeare was one of a group of playwrights, and he and they shared the expanding world of the Elizabethan voyagers and the patriotic adventures. Newton was one of the young discoveries of the Royal Society in its early days, in the restless setting which I have been describing. To know this does not of itself make us appreciate their achievement; and still less can such knowledge take the place of appreciation, in art or in science. But it does give us a context in which we can look beyond the single furrow of our own interest, into the whole fertile field of knowledge.

There never has been another moment in English history to equal the promise of that moment in the 1660s when the Royal Society was formally founded. And though it was less dramatic elsewhere, it was a high moment throughout Europe. The long tradition of astronomy in the seafaring nations was about to reach its climax, here with Newton, and in Holland with Huygens.

What was extraordinary about that moment at the Restoration? We all have a regard for Restoration times and that in itself is something of a puzzle. What exactly commands the affection in which good King Charles II's day is held? Surely not the political and literary achievements which the history books quote. The most romantic Tory could not call Charles II a great king. Dryden was great poet; nevertheless as a poet he does not rank with his predecessor Milton. As for the Restoration playwrights, by all means let us make the most of their hearty fun; but it hardly earns them a major place in English drama.

No, at bottom our regard for the period is sound because it rests on wider and less familiar achievements than these. They are scientific rather than literary achievements, but they are not specifically one or the other, any more than is Dryden's superb prose. They are the pioneer achievements of a liberal culture, and are part of a spontaneous widening of sympathy and interests throughout Europe. We can trace this even in the strange political conditions which made possible the recall of Charles II without bloodshed and with little vindictiveness after a long dictatorship born and perpetuated in blood and violence. And consider the circumstances in which, on Charles's return, the Royal Society was founded. Most of its leaders were professors of Puritan sympathies and some of them held chairs from which Cromwell had evicted the royalist holders for them. Indeed, the mathematician John Wallis owed his eminence to his skill in applying science to Cromwell's military needs: he was a pioneer in breaking enemy cyphers, and this has remained the traditional wartime service of mathematicians. Charles II cannot have relished these men, and he had no overpowering interest in science. Yet Evelyn persuaded him to give his name to their new-fangled society; and the literary men competed with them for places in it.

There is a parallel in the position of Huygens in the Académie Royale des Sciences in Paris. Christian Huygens was born in Holland in 1629. His father and his grandfather were diplomats in the service of the House of Orange. The family was friendly with Descartes, who during Huygen's youth was an exile in Holland. In the 1660s Louis XIV was already putting pressure on the House of Orange and a little later he invaded Holland. Yet Huygens, a Dutchman, a Protestant, and a Cartesian, was called to France to help found the Académie Royale in 1666, and he remained its senior official into the 1680s, when anti-Protestant policy at last became too strong for him.

Huygens' distinction and leadership were as important to the Académie as were those of Newton, who was thirteen years younger, to the Royal Society soon after. He was not the equal of Newton as a scientist; he had not quite Newton's penetration and range in mathematics or in the principles of experiment. His temper was more that of the inventor and mechanic, and the English scientist most like him was Robert Hooke, curator of experiments and secretary to the Royal Society–a slightly fantastic character, whose dislike of Newton (and Newton's dislike of him) gave an air of extravagance to the scientific arguments of the times. Like Hooke, Huygens made fundamental improvements to the clock as an aid to astronomy. Huygens in effect invented the pendulum as a time-keeping mechanism; and Hooke invented the first passable escapement for the same purpose. The work of each of them, like Newton's and like every scientist's in that uprush of invention, covered an enormous field. Huygens discovered the rings of Saturn, and the formula for centrifugal force. He did important work in mechanics and optics, and one of his merits was that he made the young Leibnitz enthusiastic for these subjects.

I have remarked that these men were not scientists alone, nor was there a barrier between their interests and those of men of other skills. Artists, writers, and scientists shared their interests and their passions. In England the fellows of the Royal Society included Robert Boyle with the poet Denham, and Samuel Pepys with the mathematician Wallis; and Sir William Petty, and Edmund Waller, and John Aubrey. The Society was interested in mathematics and fossils, in mechanics and botany, and in practical subjects from metallurgy to the statistics of population. It has a single and a universal thirst, 'to improve natural knowledge by experiment.'

What was true of England was true of the Continent of Europe. Let us take the world of Huygens as an example again, to show how all its culture was held together by the same interests. Huygens is remembered in the textbooks because he believed that light is a wave motion, and worked out the idea with success. Newton held the opposite view, that light is a stream of tiny pellets; and here Newton was wrong, although the matter is not quite a straightforward right or wrong. But the real interest of this is in recalling how wide was the influence of optics throughout the culture of the time, and widest in Holland. Huygens was a contemporary of Rembrandt, Spinoza, and the great naturalist Leeuwenhoek. Leeuwenhoek was an amateur maker of simple microscopes and was outstanding in his studies of minute nature by this mechanical and observational skill. Spinoza was a skilled lens grinder. He was a by-product of his profession (like the cobbler-poets of German tradition) but the profession gave life to Dutch discovery; Galileo himself had made his telescope in 1609, only after hearing that Dutch lens grinders could look into the distance by putting lenses together. It is not fanciful to link the daily work of these men to the attention to light which Huygens gave in his thought, and Rembrandt in his painting. Nor was this attention absent in England; the beautiful experiments with colours which Newton describes in his *Opticks* made as great an impression on painters and poets here. The landscape of the poets of the eighteenth century is far more brightly coloured than that of earlier poets. We do not always notice the sensuous flow of colours in Pope, perhaps because it springs from this forgotten interest in the spectrum. Yet Pope uses three or four times as many colour words as Shakespeare, and uses them about ten times as often.

About 1660, therefore, Europe was in the course of a great revolution in thought. This was the Scientific Revolution, and it reached into all forms of culture. We sometimes speak as if science has step by step squeezed other interests out of our culture, and is slowly strangling the traditional ways of thinking. Nothing of the kind. The Scientific Revolution in the seventeenth century was a universal revolution. Indeed it could not have begun unless there had already been a deep change in the attitude to everything natural and super-natural among thoughtful men. Puritanism in England and Protestant martyrdom on the Continent are the religious traces of that change; Marvell and Molière mark it in the arts, and Cromwell's revolution and the wars of Louis XIV are its political traces. Nor, of course, were these changes in the climate of mind without practical antecedents. At bottom, all derive from the explosion of the rigid hierarchy of land and craft which was the medieval world, by the growth of trade and industry for profit. But this regress to first causes takes us too far from the Scientific Revolution itself.

What is important here is, that the change of which the Royal Society and the Académie Royale were the visible symbols was wider and deeper than science, and had to be before such symbols could become real. Charles II and Louis XIV were not encouraging science; they merely acquiesced in a universal change of outlook. There was indeed a reaction in the next century, and one so interesting that we shall need to look at it closely. And this reaction is what makes us think of the more recent progress of science as a wholly adverse conquest. But these are the minor eddies in the flow of history. The great flood was the seventeenth century. That was the time of change, the hanging moment of instability in which men like Cromwell and Newton could remake the world. They struck the world like the Severn bore, and overthrew it instantly; but the change in outlook, the untapped head of water, had long been gathering. To see what happened about 1660, we must look at the landscape of science and thought before that time, and see what it looked like before the change quickened it.

The whole structure of thought in the Middle Ages is one which we find hard to grasp today. It was an orderly structure, but the principles by which it was ordered seem to us now outlandish and meaningless. Take such a simple question as that which is said to have turned Newton's mind to the problem of gravitation: Why does an apple when it leaves the tree fall down to the ground? The question had been asked often since the fourteenth century, when the active and enquiring men of the Italian Renaissance began to take an interest in the mechanical world. For answer, they went back to one of the great re-discoveries of the Arabs and the Renaissance, the works of the Greek philosophers. To us, this answer smacks of the most pompous tradition of philosophy, and does less to explain the world than to shuffle it in a set of tautologies. For the Middle Ages answered the question about the apple in the tradition of Aristotle: The apple falls down and not up because it is its nature to fall down.

In putting it in this way, I have of course made a caricature of the answer. I have done so not to make fun of it but, on the contrary, in order to show that even in this extravagantly naîve form, the answer is not really childish. It should be childish only if it read 'This apple falls down and not up because it is the nature of this apple at this instant to fall down.' But this is not what Aristotle said. He said that the particular apple falls down now because it is the nature of all apples to fall down at all times. Simple as this notion may seem to us, it is in itself a bold and remarkable extension of the mind. The mere creation of a permanent class of apples, the mere generalization of the concept of apples, is an act of the first importance. Of course it is simple enough to make a class of identical objects such as pennies or the capital A's in this book. But nature does not provide identical objects; on the contrary, these are always human creations. What nature provides is a tree full of apples which are all recognizable alike and yet are not identical, small apples and large ones, red ones and pale ones, apples with maggots and apples without. To make a statement about these apples together, and about crab-apples, Orange Pippins, and Beauties of Bath, is the whole basis of reasoning.

This is so important that I must underline it. The action of putting things which are not identical into a group or class is so familiar that we forget how sweeping it is. The action depends on recognizing a set of things to be alike when they are not identical. We order them by what it is that we think they have in common, which means by something that we feel to be a likeness between them. Habit makes us think the likeness obvious; it seems to us obvious that all apples are somehow alike, or all trees, or all matter. Yet there are languages in the Pacific Islands in which every tree on the island has a name, but which have no word for tree. To these islanders, trees are not all alike; on the contrary, what is important to them is that the trees are different. In the same islands men identify themselves with the totem of their clan, say with the parrot, and it seems to them plain that they are like parrots when to us the notion seems a mere artifice, and an outrageous one.

This ability to order things into likes and unlikes is, I think, the foundation of human thought. And it is a human ability; we trace and to some extent inject the likeness, which is by no means planted there by nature for all to see. Our very example of Newton's apple shows this vividly. For Newton's instant insight, as he himself told it, was precisely to see the likeness which no one else had seen, between the fall of the apple and the swing of the moon in its orbit round the earth. The theory of gravitation rests upon this; and familiar as the likeness now is to us, and obvious, it would have seemed merely fanciful to the Aristoteleans of the Middle Ages.

But, of course, the generalizations concealed within their answer did not stop at apples. What the Aristoteleans said was that the apple falls down and not up because it is the nature of earthy things always to fall down. They saw a likeness beween all masses, and they used it to order the world around them into different categories of things, earthy, watery, airy, and fiery. It was a far-reaching theory, and it was applied to the body and the mind as well as to dead matter. But what interests us now is the kind of structure which it gave to the universe. In that structure, earthy things belonged to the earth; their natural resting place was the centre of the earth; and they fell to earth in their longing for that. What buoyed the universe and kept it from finding the state of dead rest in its natural centres was the tug of war between the elements, earthy matter carried off by the action of fire, water swept up in a rush of air. The universe lived the tension between the elements, all at cross purposes because all in search of their different centres. It is a lively idea, and it is an order of nature based upon recognizable likes and unlikes. Yet to us it is now only a near fancy; the likeness on which it is built seems to us to lie in inessentials; and very bluntly it seems to us not to understand at all how the world works.

The system of the Middle Ages which had been taken from Aristotle, differs in two outstanding ways from anything that we expect of a physical system. First, it has quite different notions about matter: notions which are different in kind from ours. There are within that picture springs of action of a kind we would not dream of projecting into matter: springs of human action, where we see only the impersonal turning of a machine. Earth, water, air, and fire have natures which are at bottom human nature, and were recognized by those who made this picture as parts of human nature. What drives them is a kind of will, a mindless will perhaps, but still an obstinate animal will. Masses as it were wanted to find rest at the centre of the earth; air wanted to stream up. Abstractly Aristotle might hold that, given these natures of the elements, everything else goes on of itself. But in fact it was not meant as a mechanism or worked out as one. It grew from a view of nature as essentially animal, wilful, and alive.

Secondly, there was in the whole conception a kind of order which was really a hierarchy. Under it all runs the thought of nature as it ought to be: the order to which the great design strives, and in achieving which it would be transfigured and would come to rest. Everything reaches towards its centre, earthy things down and airy things up, because that is their stable and rightful place; yet reaching this they would come to rest, and the world would stop upon that stroke of midnight. We see how this chimes with the Greek picture of a world at rest from instant to instant; and also with the religious picture of the Middle Ages, that all worldly life is imperfection. The world is disorderly, and it seeks its order in the great ideal hierarchy of how it ought to be. And it ought to be a still perfection.

The whole picture is almost inconceivable to us. It is not inconceivable as a fable; on the contrary, as a fable it remains familiar and powerful, as we can see by looking it up for instance in the later poems of Yeats. What is inconceivable to us is that it should have been regarded in any way as doing what is asked of a scientific theory. It does not explain, we say, it does not hold together, it does not keep going, it does not make sense. We mean that his world in no way resembles the inhuman, mindless, and automatic machine which we think the world: a machine in which whatever happens does so only because something else happened before.

There in a sentence we have the difference between the outlook of, let us say (to make the example pointed), Leonardo da Vinci and Isaac Newton. Da Vinci was as great a mechanic and inventor as were Newton and his friends. Yet a glance at his notebooks shows us that what fascinated him about nature was its variety, its infinite adaptability, the fitness and the individuality of all its parts. By contrast what made astronomy a pleasure to Newton was its unity, it singleness, its model of a nature in which the diversified parts were mere disguises for the same blank atoms. And when da Vinci wanted an effect, he willed, he planned the means to make it happen: that was the purpose of his machines. But the machines of Newton (and he was a gifted experimenter) are means not for doing but for observing. He saw an effect, and he looked for its cause.

I have come thus upon the idea of causes, and made it plain that it is one face of the great division between the Middle Ages and the Scientific Age. It would be possible to make this in itself the essential division; the plan is natural and convenient. We could say that the Middle Ages saw nature as striving towards its own inner order; and that the Scientific Revolution overthrew this order and put in its place the mechanism of causes. But this does not go to the heart of the matter. On the one hand, all science, and indeed all thinking starts from and rests upon notions of order; what marks the Middle Ages is that their order was always a hierarchy. And on the other hand what marks the scientific view is not that it turned to the mechanism of causes, but that it saw the world as a mechanism at all – a machine of events. In looking at the events of high tide at Greenwich or an eclipse at the Hague, it looked not at the nature of water or fire, but looked to other events, forward and backward. The Scientific Revolution was a change from a world of things ordered according to their ideal natures, to a world of events running in a steady mechanism of before and after.

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