The Scientific Revolution:

Science and Society from the Renaissance to the Early Enlightenment

A Summer Institute for Teachers, June 13-17, 2011
Ohio State University, Columbus

Readings for Wednesday

Kepler, Galileo, and the Catholic Scientists

Kepler, *Astronomia Nova*. 44
Kepler, *Harmonices Mundi*. 45
Galileo, "Letter to the Grand Duchess of Tuscany" 49
Manuscript G3, Archive of the Sacred Congregation of the Faith 52

Secondary Sources: Tow Important Theories about the Scientific Revolution: Thomas Kuhn and Frances A. Yates

Kuhn, *Structure of Scientific Revolutions*, Introduction. 54
Yates, "The Hermetic Tradition in Renaissance Science" 59

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the sky acts in precisely the same way upon all those born at one and the same time, but that they are subject to diversity and are altered in different ways by heavenly influences. Very often the influence of the stars is shifted about in different ways for different reasons, such as upbringing, schooling, conversation and similar changing circumstances in life. Nor is man's free will in any way made subordinate to the stars but through it, under the guidance of reason, he can do very many things beyond the influence of the stars, if that is what he wishes. Astrologers do not require everyone to receive the influences of the stars in the same way, but some more and some less, according to their aptitude for receiving them or their immunity to them.... Theologians do not take into consideration that astrologers do not bind people's will to the stars, but agree that there is something in humanity which has been raised above all the stars and whose beneficial effect is that if people wish to live as true and supra-mundane human beings, they can conquer whatever malevolent inclinations they may have from the stars. But if they choose to live a brutish life, to be carried along by blind emotions, and prefer to fornicate with the beasts, they must not think God is the author of this mistake; for God created human beings in such a way that they can, if they wish, overcome all malevolent inclinations they get from the stars.

3.4 J. Kepler, *Astronomia Nova*, Heidelberg, 1609, trans. C. A. Russell, in ~~D. C. Goodman~~ (ed.), *Science and Religious Belief, 1600–1900: A Selection of Primary Sources* (John Wright and Open University Press, 1973), pp. 22–3

See Chapter 10 of my *Astronomy: the Optical Section* where you will find reasons why the sun in this way seems to all men to be moving, but not the earth: namely, because the sun seems small, but the earth truly appears to be large. Nor is the motion of the sun to be grasped by sight (since it gives the appearance of being slow) but by reason alone on account of the changed relationship to the mountains after some time. It is therefore impossible that reason not previously instructed should imagine anything other than that the earth is a kind of vast house with the vault of the sky placed on top of it; it is motionless and within it the sun being so small passes from one region to another, like a bird wandering through the air.

This universal image has produced the first line in the sacred page. *In the beginning*, said Moses, *God created the heaven and the earth*; this is a natural expression because these two aspects of the universe are those that chiefly meet the eye. It is as if Moses were saying to man 'all this architecture of the universe that you see, the brightness above, by which you are covered, the widespreading darkness below, upon which you stand – all this had been created by God'.

In other places man is questioned whether he has learned how to penetrate the height of the sky above or the depth of the earth beneath. This is natural because to the mass of men each of these appears equally to project

into infinite space. Nevertheless, there never was a man who, listening rationally, would use these words to circumscribe the diligence of the astronomers, whether in demonstrating the most contemptible weakness of the earth by comparison with the sky, or through investigations of astronomical distance. These words do not speak about intellectualised dimensions, but about the dimension of reality – which, for a human body fixed on the earth and drinking in the free air, is totally impossible. Read the whole of Job Ch. 38 and compare with it the matters that are disputed in astronomy and physics.

If anyone alleges on the basis of Psalm 24 *The earth is founded upon the seas* (in order to establish some new philosophical dictum, however absurd to hear) that the earth is floating on the waters, may it not be rightly said to him that he ought to set free the Holy Spirit and should not drag Him in to the schools of physics to make a fool of Him. For in that place the Psalmist wishes to suggest nothing other than what men know beforehand and experience each day: the lands, uplifted after separation of the waters, have great rivers flowing through them and the seas around them on all sides. Doubtless the same is spoken of elsewhere, when the Israelites sing *By the waters of Babylon there we sat down*, i.e., by the side of the rivers, or on the banks of the Euphrates and Tigris.

If anyone receives the one freely, why not the other, so that in other places which are often quoted against the motion of the earth we should, in the same way, turn our eyes from physics to the tradition of scripture?

One generation passes away, says Ecclesiastes, *and another generation is born*, but the earth abides for ever. Is Solomon here, as it were, disputing with the astronomers? No, he is rather warning men of their changeableness whereas the earth, the home of the human race, always remains the same; the movement of the sun keeps returning it to its starting-point; the wind is driven in a circle, and returns to the same plan; rivers flow from their sources to the sea, and thence return to their sources. Finally, while some men perish others are born, and always the drama of life is the same; there is nothing new under the sun.

You are listening to no new principle of physics. It is a question of ethical instruction in a matter which is clear on its own, observed universally but receives scant consideration. That is why Solomon insists on the matter. Who does not know the earth to be always the same? Who does not see that the sun rising daily in the East, that the rivers run perpetually down to the sea, that the pattern of changes of the wind is fixed and recurring and that one generation succeeds another? Who in fact considers that the drama of life is being perpetually performed, with only a change of cast and that there is nothing new in human affairs? And so, by rehearsing things which everyone sees, Solomon warns of that which the majority wrongly neglect.

But some men think Psalm 104 to be wholly concerned with physics, since it is wholly concerned with physical matters. And there God is said to have

laid the foundations of the earth so that it should not be moved, and that stability will remain from age to age. Nevertheless the Psalmist is a very long way from speculation about physical causes. He rests utterly in the greatness of God who made all these things and is unfolding a hymn to God the Creator, a hymn in which he runs in order through the whole world as it appears to our eyes.

3.5 Johannes Kepler, *Harmonices Mundi* (*The Harmonies of the World*), 1619, trans. C. G. Wallis, in *Great Books of the World*, vol. 16 (Chicago: Encyclopaedia Britannica Inc., 1952), pp. 1014–18, 1040–1

3. A Summary of Astronomical Doctrine Necessary for Speculation into the Celestial Harmonies

First of all, my readers should know that the ancient astronomical hypotheses of Ptolemy, in the fashion in which they have been unfolded in the *Theoricae* of Peurbach and by the other writers of epitomes, are to be completely removed from this discussion and cast out of the mind. For they do not convey the true lay out of the bodies of the world and the polity of the movements.

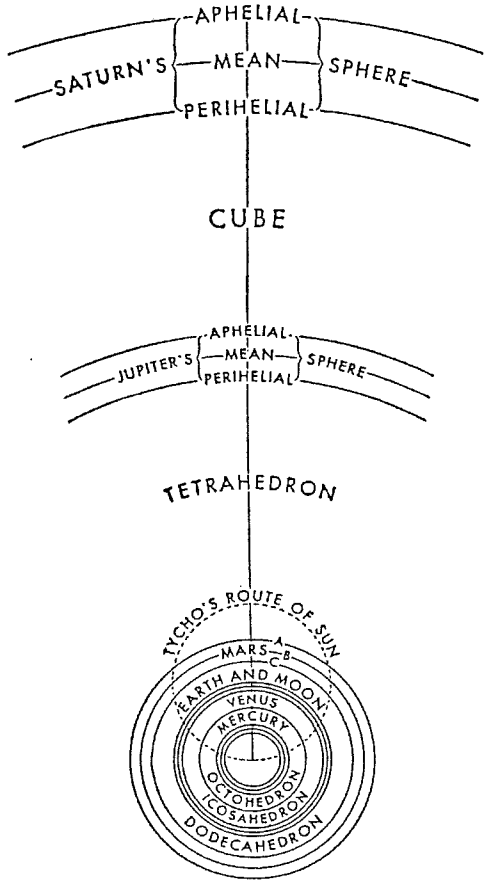
Although I cannot do otherwise than to put solely Copernicus' opinion concerning the world in the place of those hypotheses and, if that were possible, to persuade everyone of it; but because the thing is still new among the mass of the intelligentsia [*apud vulgus studiosorum*], and the doctrine that the Earth is one of the planets and moves among the stars around a motionless sun sounds very absurd to the ears of most of them: therefore those who are shocked by the unfamiliarity of this opinion should know that these harmonical speculations are possible even with the hypotheses of Tycho Brahe – because that author holds, in common with Copernicus, everything else which pertains to the lay out of the bodies and the tempering of the movements, and transfers solely the Copernican annual movement of the Earth to the whole system of planetary spheres and to the sun, which occupies the centre of that system, in the opinion of both authors. For after this transference of movement it is nevertheless true that in Brahe the Earth occupies at any time the same place that Copernicus gives it, if not in the very vast and measureless region of the fixed stars, at least in the system of the planetary world. And accordingly, just as he who draws a circle on paper makes the writing-foot of the compass revolve, while he who fastens the paper or tablet to a turning lathe draws the same circle on the revolving tablet with the foot of the compass or stylus motionless; so too, in the case of Copernicus the Earth, by the real movement of its body, measures out a circle revolving midway between the circle of Mars on the outside and that of Venus on the inside; but in the case of Tycho Brahe the whole planetary system (wherein among the rest the circles of Mars and Venus are found) revolves like a tablet on a lathe and applies to the motionless Earth,

or to the stylus on the lathe, the midspace between the circles of Mars and Venus; and it comes about from this movement of the system that the Earth within it, although remaining motionless, marks out the same circle around the sun and midway between Mars and Venus, which in Copernicus it marks out by the real movement of its body while the system is at rest. Therefore, since harmonic speculation considers the eccentric movements of the planets, as if seen from the sun, you may easily understand that if any observer were stationed on a sun as much in motion as you please, nevertheless for him the Earth, although at rest (as a concession to Brahe), would seem to describe the annual circle midway between the planets and in an intermediate length of time. Wherefore, if there is any man of such feeble wit that he cannot grasp the movement of the earth among the stars, nevertheless he can take pleasure in the most excellent spectacle of this most divine construction, if he applies to their image in the sun whatever he hears concerning the daily movements of the Earth in its eccentric – such an image as Tycho Brahe exhibits, with the Earth at rest.

And nevertheless the followers of the true Samian philosophy have no just cause to be jealous of sharing this delightful speculation with such persons, because their joy will be in many ways more perfect, as due to the consummate perfection of speculation, if they have accepted the immobility of the sun and the movement of the earth.

Firstly [I], therefore, let my readers grasp that today it is absolutely certain among all astronomers that all the planets revolve around the sun, with the exception of the moon, which alone has the Earth as its centre: the magnitude of the moon's sphere or orbit is not great enough for it to be delineated in this diagram in a just ratio to the rest. Therefore, to the other five planets, a sixth, the Earth, is added, which traces a sixth circle around the sun, whether by its own proper movement with the sun at rest, or motionless itself and with the whole planetary system revolving.

Secondly [II]: It is also certain that all the planets are eccentric, *i.e*, they change their distances from the sun, in such fashion that in one part of their circle they become farthest away from the sun, and in the opposite part they come nearest to the sun. In the accompanying diagram three circles apiece have been drawn for the single planets: none of them indicate the eccentric route of the planet itself; but the mean circle, such as *BE* in the case of Mars, is equal to the eccentric orbit, with respect to its longer diameter. But the orbit itself, such as *AD*, touches *AF*, the upper of the three, in one place *A*, and the lower circle *CD*, in the opposite place *D*. The circle *GH* made with dots and described through the centre of the sun indicates the route of the sun according to Tycho Brahe. And if the sun moves on this route, then absolutely all the points in this whole planetary system here depicted advance upon an equal route, each upon his own. And with one point of it (namely, the centre of the sun) stationed at one point of its circle, as here at the lowest, absolutely each and every point of the system will be stationed at the lowest part of its circle. However, on account of the

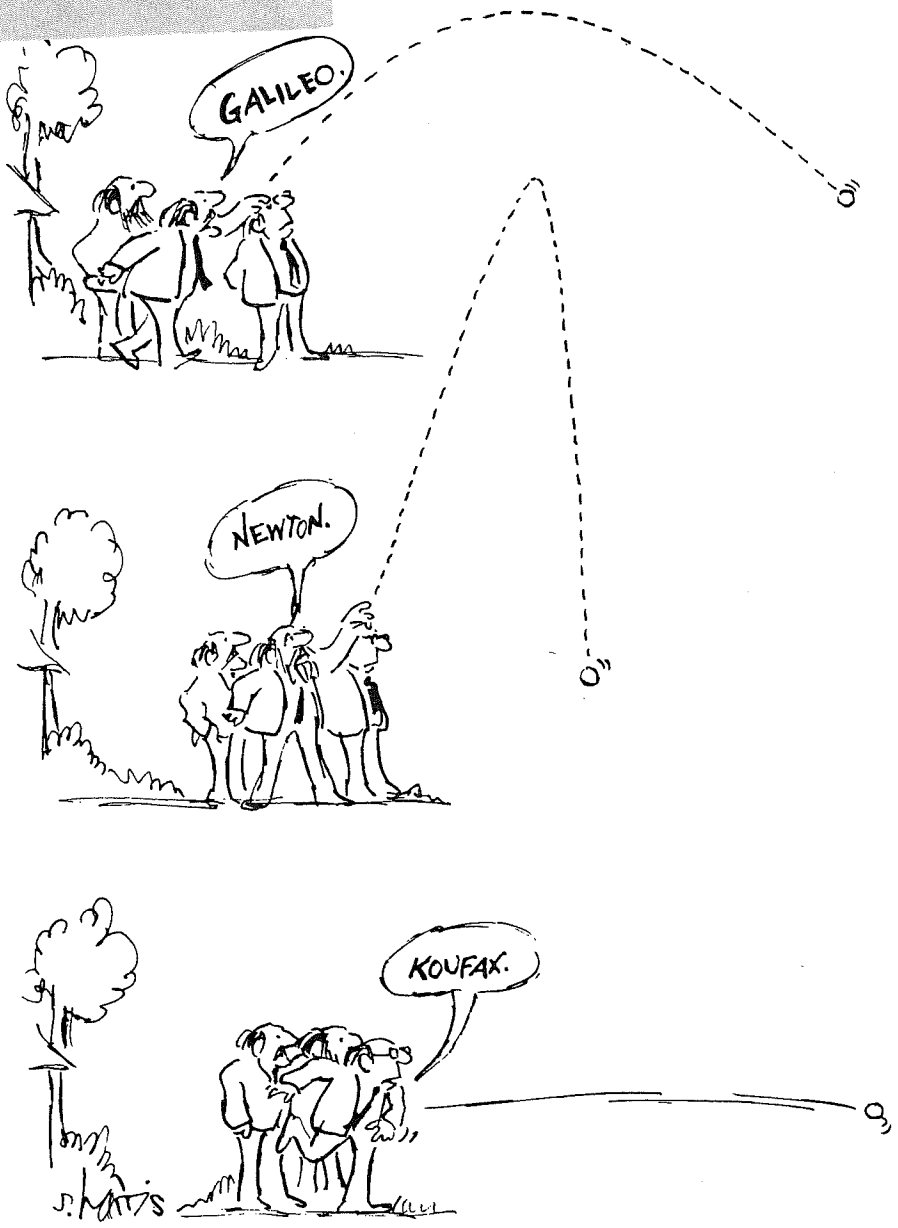


smallness of the space the three circles of Venus unite in one, contrary to my intention.

Thirdly [III]: Let the reader recall from my *Mysterium Cosmographicum*, which I published twenty-two years ago, that the number of the planets or circular routes around the sun was taken by the very wise Founder from the five regular solids, concerning which Euclid, so many ages ago, wrote his book which is called the *Elements* in that it is built up out of a series of propositions. But it has been made clear in the second book of this work

that there cannot be more regular bodies, *i.e.*, that regular plane figures cannot fit together in a solid more than five times.

Fourthly [IV]: As regards the ratio of the planetary orbits, the ratio between two neighbouring planetary orbits is always of such a magnitude that it is easily apparent that each and every one of them approaches the single ratio of the spheres of one of the five regular solids, namely, that of the sphere circumscribing to the sphere inscribed in the figure. Nevertheless it is not wholly equal, as I once dared to promise concerning the final perfection of astronomy. For, after completing the demonstration of the intervals from Brahe's observations, I discovered the following: if the angles of the cube are applied to the inmost circle of Saturn, the centres of the planes are approximately tangent to the middle circle of Jupiter; and if the angles of the tetrahedron are placed against the inmost circle of Jupiter, the centres of the planes of the tetrahedron are approximately tangent to the outmost circle of Mars; thus if the angles of the octahedron are placed against any circle of Venus (for the total interval between the three has been very much reduced), the centres of the planes of the octahedron penetrate and descend deeply within the outmost circle of Mercury, but nonetheless do not reach as far as the middle circle of Mercury; and finally, closest of all to the ratios of the dodecahedral and icosahedral spheres – which ratios are equal to one another – are the ratios or intervals between the circles of Mars and the Earth, and the Earth and Venus; and those intervals are similarly equal, if we compute from the inmost circle of Mars to the middle circle of the Earth, but from the middle circle of the Earth to the middle circle of Venus. For the middle distance of the Earth is a mean proportional between the least distance of Mars and the middle distance of Venus. However, these two ratios between the planetary circles are still greater than the ratios of those two pairs of spheres in the figures, in such fashion that the centres of the dodecahedral planes are not tangent to the outmost circle of the Earth, and the centres of the icosahedral planes are not tangent to the outmost circle of Venus; nor, however, can this gap be filled by the semidiameter of the lunar sphere, by adding it, on the upper side, to the greatest distance of the Earth and subtracting it, on the lower, from the least distance of the same. But I find a certain other ratio of figures – namely, if I take the augmented dodecahedron, to which I have given the name of echinus, (as being fashioned from twelve quinquangular stars and thereby very close to the five regular solids), if I take it, I say, and place its twelve points in the inmost circle of Mars, then the sides of the pentagons, which are the bases of the single rays or points, touch the middle circle of Venus. In short: the cube and the octahedron, which are consorts, do not penetrate their planetary spheres at all; the dodecahedron and the icosahedron, which are consorts, do not wholly reach to theirs, the tetrahedron exactly touches both: in the first case there is falling short; in the second, excess; and in the third, equality, with respect to the planetary intervals.


GALILEO.
0"
NEWTON.
0"
KOUFAX.
0'
J. Harris


If left to itself a body will move with uniform velocity in one and the same direction.
GALILEO – I SAID A RIGHT AT THE CORNER, AND THEN A LEFT!

Chapter Four
Crisis in Italy

4.1 (a) Galileo, *Letter to the Grand Duchess Christina* [1615], 1636, and (b) Cardinal Bellarmine, letter to Paolo Foscarini, 12 April 1615, both trans. Stillman Drake in *Discoveries and Opinions of Galileo* (New York: Doubleday, 1957), pp. 181–200, 162–4

***(a) Galileo,* Letter to the Grand Duchess Christina**

The reason produced for condemning the opinion that the earth moves and the sun stands still is that in many places in the Bible one may read that the sun moves and the earth stands still. Since the Bible cannot err, it follows as a necessary consequence that anyone takes an erroneous and heretical position who maintains that the sun is inherently motionless and the earth movable.

With regard to this argument, I think in the first place that it is very pious to say and prudent to affirm that the holy Bible can never speak untruth – whenever its true meaning is understood. But I believe nobody will deny that it is often very abstruse, and may say things which are quite different from what its bare words signify. Hence in expounding the Bible if one were always to confine oneself to the unadorned grammatical meaning, one might fall into error. Not only contradictions and propositions far from true might thus be made to appear in the Bible, but even grave heresies and follies. Thus it would be necessary to assign to God feet, hands, and eyes, as well as corporeal and human affections, such as anger, repentance, hatred, and sometimes even the forgetting of things past and ignorance of those to come. These propositions uttered by the Holy Ghost were set down in that manner by the sacred scribes in order to accommodate them to the capacities of the common people, who are rude and unlearned. For the sake of those who deserve to be separated from the herd, it is necessary that wise expositors should produce the true senses of such passages, together with the special reasons for which they were set down in these words. This doctrine is so

THE
Ancient and Modern
DOCTRINE
OF
Holy Fathers,
AND
Iudicious Divines,
CONCERNING
The rash citation of the Testimony of SACRED SCRIPTURE, in Conclusions meerly Natural, and that may be proved by Sensible Experiments, and Necessary Demonstrations.

Written, some years since, to Gratifie The most SERENE CHRISTINA LOTHARINGA, *Arch-Dutchess of TUSCANY*;
By GALILÆO GALILÆI, A Gentleman of *Florence*, and Chief Philosopher and Mathematician to His most Serene Highness the Grand *DUKE*.

And now rendred into English from the Italian,
BY
THOMAS SALUSBURY.

Naturam Rerum invenire, difficile; & ubi invenerit, indicare in vulgus, nefas. Plato.

LONDON,
Printed by WILLIAM LEYBOURN, 1661.
Hhh

The title-page of Galileo's Letter to the Grand Duchess *in Thomas Salusbury's translation,* Mathematical Collections *(London, 1661).*

widespread and so definite with all theologians that it would be superfluous to adduce evidence for it.

Hence I think that I may reasonably conclude that whenever the Bible has occasion to speak of any physical conclusion (especially those which are very abtruse and hard to understand), the rule has been observed of avoiding

confusion in the minds of the common people which would render them contumacious toward the higher mysteries. Now the Bible, merely to condescend to popular capacity, has not hesitated to obscure some very important pronouncements, attributing to God himself some qualities extremely remote from (and even contrary to) His essence. Who, then, would positively declare that this principle has been set aside, and the Bible has confined itself rigorously to the bare and restricted sense of its words, when speaking but casually of the earth, of water, of the sun, or of any other created thing? Especially in view of the fact that these things in no way concern the primary purpose of the sacred writings, which is the service of God and the salvation of souls – matters infinitely beyond the comprehension of the common people.

This being granted, I think that in discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations; for the holy Bible and the phenomena of nature proceed alike from the divine Word, the former as the dictate of the Holy Ghost and the latter as the observant executrix of God's commands. It is necessary for the Bible, in order to be accommodated to the understanding of every man, to speak many things which appear to differ from the absolute truth so far as the bare meaning of the words is concerned. But Nature, on the other hand, is inexorable and immutable; she never transgresses the laws imposed upon her, or cares a whit whether her abstruse reasons and methods of operation are understandable to men. For that reason it appears that nothing physical which sense-experience sets before our eyes, or which necessary demonstrations prove to us, ought to be called in question (much less condemned) upon the testimony of biblical passages which may have some different meaning beneath their words. For the Bible is not chained in every expression to conditions as strict as those which govern all physical effects; nor is God any less excellently revealed in Nature's actions than in the sacred statements of the Bible. [...]

But I do not feel obliged to believe that that same God who has endowed us with senses, reason, and intellect has intended to forgo their use and by some other means to give us knowledge which we can attain by them. He would not require us to deny sense and reason in physical matters which are set before our eyes and minds by direct experience or necessary demonstrations. This must be especially true in those sciences of which but the faintest trace (and that consisting of conclusions) is to be found in the Bible. Of astronomy, for instance, so little is found that none of the planets except Venus are so much as mentioned, and this only once or twice under the name of 'Lucifer'. If the sacred scribes had had any intention of teaching people certain arrangements and motions of the heavenly bodies, or had they wished us to derive such knowledge from the Bible, then in my opinion they would not have spoken of these matters so sparingly in comparison with the infinite number of admirable conclusions which are demonstrated

in that science. Far from pretending to teach us the constitution and motions of the heavens and the stars, with their shapes, magnitudes, and distances, the authors of the Bible intentionally forbore to speak of these things, though all were quite well known to them. [...]

Let us grant then that theology is conversant with the loftiest divine contemplation, and occupies the regal throne among sciences by dignity. But acquiring the highest authority in this way, if she does not descend to the lower and humbler speculations of the subordinate sciences and has no regard for them because they are not concerned with blessedness, then her professors should not arrogate to themselves the authority to decide on controversies in professions which they have neither studied nor practiced. Why, this would be as if an absolute despot, being neither a physician nor an architect but knowing himself free to command, should undertake to administer medicines and erect buildings according to his whim – at grave peril of his poor patients' lives, and the speedy collapse of his edifices.

Again, to command that the very professors of astronomy themselves see to the refutation of their own observations and proofs as mere fallacies and sophisms is to enjoin something that lies beyond any possibility of accomplishment. For this would amount to commanding that they must not see what they see and must not understand what they know, and that in searching they must find the opposite of what they actually encounter. Before this could be done they would have to be taught how to make one mental faculty command another, and the inferior powers the superior, so that the imagination and the will might be forced to believe the opposite of what the intellect understands. I am referring at all times to merely physical propositions, and not to supernatural things which are matters of faith.

I entreat those wise and prudent Fathers to consider with great care the difference that exists between doctrines subject to proof and those subject to opinion. Considering the force exerted by logical deductions, they may ascertain that it is not in the power of the professors of demonstrative sciences to change their opinions at will and apply themselves first to one side and then to the other. There is a great difference between commanding a mathematician or a philosopher and influencing a lawyer or a merchant, for demonstrated conclusions about things in nature or in the heavens cannot be changed with the same facility as opinions about what is or is not lawful in a contract, bargain, or bill of exchange. [...]

Now if truly demonstrated physical conclusions need not be subordinated to biblical passages, but the latter must rather be shown not to interfere with the former, then before a physical proposition is condemned it must be shown to be not rigorously demonstrated – and this is to be done not by those who hold the proposition to be true, but by those who judge it to be false. This seems very reasonable and natural, for those who believe an argument to be false may much more easily find the fallacies in it than men who consider it to be true and conclusive. Indeed, in the latter case it will happen that the more the adherents of an opinion turn over their pages,

examine the arguments, repeat the observations, and compare the experiences, the more they will be confirmed in that belief. And Your Highness knows what happened to the late mathematician of the University of Pisa who undertook in his old age to look into the Copernican doctrine in the hope of shaking its foundations and refuting it, since he considered it false only because he had never studied it. As it fell out, no sooner had he understood its grounds, procedures, and demonstrations than he found himself persuaded, and from an opponent he became a very staunch defender of it. I might also name other mathematicians who, moved by my latest discoveries, have confessed it necessary to alter the previously accepted system of the world, as this is simply unable to subsist any longer.

If in order to banish the opinion in question from the world it were sufficient to stop the mouth of a single man – as perhaps those men persuade themselves who, measuring the minds of others by their own, think it impossible that this doctrine should be able to continue to find adherents – then that would be very easily done. But things stand otherwise. To carry out such a decision it would be necessary not only to prohibit the book of Copernicus and the writings of other authors who follow the same opinion, but to ban the whole science of astronomy. Furthermore, it would be necessary to forbid men to look at the heavens, in order that they might not see Mars and Venus sometimes quite near the earth and sometimes very distant, the variation being so great that Venus is forty times and Mars sixty times as large at one time as another. And it would be necessary to prevent Venus being seen round at one time and forked at another, with very thin horns; as well as many other sensory observations which can never be reconciled with the Ptolemaic system in any way, but are very strong arguments for the Copernican. And to ban Copernicus now that his doctrine is daily reinforced by many new observations and by the learned applying themselves to the reading of his book, after this opinion has been allowed and tolerated for those many years during which it was less followed and less confirmed, would seem in my judgment to be a contravention of truth, and an attempt to hide and suppress her the more as she revealed herself the more clearly and plainly. Not to abolish and censure his whole book, but only to condemn as erroneous this particular proposition, would (if I am not mistaken) be a still greater detriment to the minds of men, since it would afford them occasion to see a proposition proved that it was heresy to believe. [...]

Regarding the state of rest or motion of the sun and earth, experience plainly proves that in order to accommodate the common people it was necessary to assert of these things precisely what the words of the Bible convey. Even in our own age, people far less primitive continue to maintain the same opinion for reasons which will be found extremely trivial if well weighed and examined, and upon the basis of experiences that are wholly false or altogether beside the point. Nor is it worth while to try to change their opinion, they being unable to understand the arguments on the opposite

side, for these depend upon observations too precise and demonstrations too subtle, grounded on abstractions which require too strong an imagination to be comprehended by them. Hence even if the stability of heaven and the motion of the earth should be more than certain in the minds of the wise, it would still be necessary to assert the contrary for the preservation of belief among the all-too-numerous vulgar. Among a thousand ordinary men who might be questioned concerning these things, probably not a single one will be found to answer anything except that it looks to him as if the sun moves and the earth stands still, and therefore he believes this to be certain. But one need not on that account take the common popular assent as an argument for the truth of what is stated; for if we should examine these very men concerning their reasons for what they believe, and on the other hand listen to the experiences and proofs which induce a few others to believe the contrary, we should find the latter to be persuaded by very sound arguments, and the former by simple appearances and vain or ridiculous impressions.

It is sufficiently obvious that to attribute motion to the sun and rest to the earth was therefore necessary lest the shallow minds of the common people should become confused, obstinate, and contumacious in yielding assent to the principal articles that are absolutely matters of faith. And if this was necessary, there is no wonder at all that it was carried out with great prudence in the holy Bible. I shall say further that not only respect for the incapacity of the vulgar, but also current opinion in those times, made the sacred authors accommodate themselves (in matters unnecessary to salvation) more to accepted usage than to the true essence of things. [...]

(b) Cardinal Bellarmine, letter to Paolo Foscarini, 12 April 1615

I have gladly read the letter in Italian and the essay in Latin that Your Reverence has sent me, and I thank you for both, confessing that they are filled with ingenuity and learning. But since you ask for my opinion, I shall give it to you briefly, as you have little time for reading and I for writing.

First. I say that it appears to me that Your Reverence and Sig. Galileo did prudently to content yourselves with speaking hypothetically and not positively, as I have always believed Copernicus did. For to say that assuming the earth moves and the sun stands still saves all the appearances better than eccentrics and epicycles is to speak well. This has no danger in it, and it suffices for mathematicians. But to wish to affirm that the sun is really fixed in the centre of the heavens and merely turns upon itself without travelling from east to west, and that the earth is situated in the third sphere and revolves very swiftly around the sun, is a very dangerous thing, not only by irritating all the theologians and scholastic philosophers, but also by injuring our holy faith and making the sacred Scripture false. For

word. I believe that no more solid an existence belongs to many qualities which we have come to attribute to physical bodies – tastes, odors, colors, and many more.

A body which is solid and, so to speak, quite material, when moved in contact with any part of my person produces in me the sensation we call touch. This, though it exists over my entire body, seems to reside principally in the palms of the hands and in the finger tips, by whose means we sense the most minute differences in texture that are not easily distinguished by other parts of our bodies. Some of these sensations are more pleasant to us than others.... The sense of touch is more material than the other sense; and, as it arises from the solidity of matter, it seems to be related to the earthly element.

Perhaps the origin of two other senses lies in the fact that there are bodies which constantly dissolve into minute particles, some of which are heavier than air and descend, while others are lighter and rise up. The former may strike upon a certain part of our bodies that is much more sensitive than the skin, which does not feel the invasion of such subtle matter. This is the upper surface of the tongue; here the tiny particles are received, and mixing with and penetrating its moisture, they give rise to tastes, which are sweet or unsavory according to the various shapes, numbers, and speeds of the particles. And those minute particles which rise up may enter by our nostrils and strike upon some small protuberances which are the instrument of smelling; here likewise their touch and passage is received to our like or dislike according as they have this or that shape, are fast or slow, and are numerous or few. The tongue and nasal passages are providently arranged for these things, as the one extends from below to receive descending particles, and the other is adapted to those which ascend. Perhaps the excitation of tastes may be given a certain analogy to fluids, which descend through air, and odors to fires, which ascend.

Then there remains the air itself, an element available for sounds, which come to us indifferently from below, above, and all sides – for we reside in the air and its movements displace it equally in all directions. The location of the ear is most fittingly accommodated to all positions in space. Sounds are made and heard by us when the air – without any special property of 'sonority' or 'transonority' – is ruffled by a rapid tremor into very minute waves and moves certain cartilages of a tympanum in our ear. External means capable of thus ruffling the air are very numerous, but for the most part they may be reduced to the trembling of some body which pushes the air and disturbs it. Waves are propagated very rapidly in this way, and high tones are produced by frequent waves and low tones by sparse ones.

To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, numbers, and slow or rapid movements. I think that if ears, tongues, and noses were removed, shapes and numbers

and motions would remain, but not odors or tastes or sounds. The latter, I believe, are nothing more than names when separated from living beings, just as tickling and titillation are nothing but names in the absence of such things as noses and armpits....

Having shown that many sensations which are supposed to be qualities residing in external objects have no real existence save in us, and outside ourselves are mere names, I now say that I am inclined to believe heat to be of this character. Those materials which produce heat in us and make us feel warmth, which are known by the general name of 'fire', would then be a multitude of minute particles having certain shapes and moving with certain velocities. Meeting with our bodies, they penetrate by means of their extreme subtlety, and their touch as felt by us when they pass through our substance is the sensation we call 'heat'. This is pleasant or unpleasant according to the greater or smaller speed of these particles as they go pricking and penetrating; pleasant when this assists our necessary transpiration, and obnoxious when it causes too great a separation and dissolution of our substance. The operation of fire by means of its particles is merely that in moving it penetrates all bodies, causing their speedy or slow dissolution in proportion to the number and velocity of the fire-corpuscles and the density or tenuity of the bodies....

4.3 MS G3 in the Archive of the Sacred Congregation for the Doctrine of the Faith, ser. AD EE [1624?], trans. P. Rosenthal in P. Redondi, *Galileo Heretic* (London: Allen Lane, 1988), pp. 333–5

Having in past days perused Signor Galileo Galilei's book entitled *The Assayer*, I have come to consider a doctrine already taught by certain ancient philosophers and effectively rejected by Aristotle, but renewed by the same Signor Galilei. And having decided to compare it with the true and undoubted Rule of revealed doctrines, I have found that in the Light of that Lantern which by the exercise and merit of our faith shines out indeed in murky places, and which more securely and more certainly than any natural evidence illuminates us, this doctrine appears false, or even (which I do not judge) very difficult and dangerous. So that he who receives the Rule as true must not falter in speech and in the judgment of more serious matters, I have therefore thought to propose it to you, Very Reverend Father, and beg you, as I am doing, to tell me its meaning, which will serve as my warning.

Therefore, the aforesaid Author, in the book cited (on page 196, line 29), wishing to explain that proposition proffered by Aristotle in so many places – that motion is the cause of heat – and to adjust it to his intention, sets out to prove that these accidents which are commonly called colors, odors, tastes, etc., on the part of the subject, in which it is commonly believed that they are found, are nothing but pure words and are only in the sensitive body of the animal that feels them. He explains this with the example of the

Tickle, or let us say Titillation, caused by touching a body in certain parts, concluding that like the tickle, as far as the action goes, once having removed the animal's sensitivity, it is no different from the touch and movement that one makes on a marble statue, for everything is our subjective experience; thus, these accidents which are apprehended by our senses and are called tastes, smells, colors, etc., are not, he says, subjects as one holds them generally to be, but only our senses, since the titillation is not in the hand or in the feather, which touches, for example, the sole of the foot, but solely in the animal's sensitive organ.

But this discourse seems to me to be at fault in taking as proved that which it must prove, i.e. that in all cases the object which we feel is in us, because the act that is involved is in us. It is the same as saying: the sight with which I see the light of the sun is in me; therefore, the light of the sun is in me. What might be the meaning of such reasoning, however, I shall not pause to examine.

The author then goes on to explain his Doctrine, and does his best to demonstrate what these accidents are in relation to the object and the end of our actions; and as one can see on page 198, line 12, he begins to explain them with the atoms of Anaxagoras or of Democritus, which he calls minims or minimal particles; and in these, he says continually, are resolved the bodies, which, however, applied to our senses penetrate our substance, and according to the diversity of the touches, and the diverse shapes of those minims, smooth or rough, hard or yielding, and according to whether they are few or many, prick us differently, and piercing with greater or lesser division, or by making it easier for us to breathe, and hence our irritation or pleasure. To the more material or corporeal sense of touch, he says, the minims of earth are most appropriate. To the taste, those of water and he calls them fluids; to the smell, those of fire and he calls them fiery particles; to the hearing, those of the air; and to the sight he then attributes the light, about which he says he has little to say. And on page 199, line 25, he concludes that in order to arouse in us tastes, smells, etc., all that is needed in bodies which commonly are tasteful, odorous, etc. are sizes, many varied shapes; and that the smells, tastes, colors, etc. are nowhere but in the eyes, tongues, noses, etc., so that once having taken away those organs, the aforesaid accidents are not distinguished from atoms except in name.

Now if one admits this philosophy of accidents as true, it seems to me, that makes greatly difficult the existence of the accidents of the bread and wine which in the Most Holy Sacrament are separated from their substance; since finding again therein the terms, and the objects of touch, sight, taste, etc., one will also have to say according to this doctrine that there are the very tiny particles with which the substance of the bread first moved our senses, which if they were substantial (as Anaxagoras said, and this author seems to allow on page 200, line 28), it follows that in the Sacrament there are substantial parts of bread or wine, which is

the error condemned by the Sacred Tridentine Council, Session 13, Canon 2.

Or actually, if they were only sizes, shapes, numbers, etc., as he also seems clearly to admit, agreeing with Democritus, it follows that all these are accidental modes, or, as others say, shapes of quantity. While the Sacred Councils, and especially the Trident Council in the passage cited, determine that after the Consecration there remain in the Sacrament only the Accidents of the bread and wine, he instead says that there only remains the quantity with triangular shapes, acute or obtuse, etc., and that with these accidents alone is saved the existence of accidents or sensible species – which consequence seems to me not only in conflict with the entire communion of Theologians who teach us that in the Sacrament remain all the sensible accidents of bread, wine, color, smell, and taste, and not mere words, but also, as is known, with the good *judgment* that the quantity of the substance does not remain. Again, this is inevitably repugnant to the truth of the Sacred Councils; for, whether these minims are explained with Anaxagoras or Democritus, if they remain after the Consecration there will not be less substance of the bread in a consecrated host than in an unconsecrated host, since to be corporeal substance, in their opinion, consists, in an aggregation of atoms in this or that fashion, with this or that shape, etc. But if these particles do not remain, it follows that no accident of bread remains in the consecrated Host; since other accidents do not emerge, this Author says on page 197, line 1, that shapes, sizes, movements, etc. do so, and (these being the effects of a quantity or quantum substance) it is not possible, as all philosophers and Theologians teach, to separate them in such a way that they would exist without the substance or quantity of which they are accidents.

And this is what seems to me difficult in this Doctrine; and I propose and submit it, as regards my already expressed judgment, to what you, Most Reverend Father, will be pleased to tell and to which I make obeisance.

4.4 Galileo, *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican*, 1632, trans. Stillman Drake (Berkeley, CA: University of California Press, 1962), pp. 139, 141–2, 144–9

SALV. . . . Aristotle says, then, that a most certain proof of the earth's being motionless is that things projected perpendicularly upward are seen to return by the same line to the same place from which they were thrown, even though the movement is extremely high. This, he argues, could not happen if the earth moved, since in the time during which the projectile is moving upward and then downward it is separated from the earth, and the place from which the projectile began its motion would go a long way toward the east, thanks to the revolving of the earth, and the falling

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INTERNATIONAL ENCYCLOPEDIA of UNIFIED SCIENCE

The Structure of Scientific Revolutions

Second Edition, Enlarged

Thomas S. Kuhn

VOLUMES I AND II · FOUNDATIONS OF THE UNITY OF SCIENCE
VOLUME II · NUMBER 2

THE UNIVERSITY OF CHICAGO PRESS

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Since that version was drafted, many other friends have helped with its reformulation. They will, I think, forgive me if I name only the four whose contributions proved most far-reaching and decisive: Paul K. Feyerabend of Berkeley, Ernest Nagel of Columbia, H. Pierre Noyes of the Lawrence Radiation Laboratory, and my student, John L. Heilbron, who has often worked closely with me in preparing a final version for the press. I have found all their reservations and suggestions extremely helpful, but I have no reason to believe (and some reason to doubt) that either they or the others mentioned above approve in its entirety the manuscript that results.

My final acknowledgments, to my parents, wife, and children, must be of a rather different sort. In ways which I shall probably be the last to recognize, each of them, too, has contributed intellectual ingredients to my work. But they have also, in varying degrees, done something more important. They have, that is, let it go on and even encouraged my devotion to it. Anyone who has wrestled with a project like mine will recognize what it has occasionally cost them. I do not know how to give them thanks.

T. S. K.

Berkeley, California
February 1962

I. Introduction: A Role for History

History, if viewed as a repository for more than anecdote or chronology, could produce a decisive transformation in the image of science by which we are now possessed. That image has previously been drawn, even by scientists themselves, mainly from the study of finished scientific achievements as these are recorded in the classics and, more recently, in the textbooks from which each new scientific generation learns to practice its trade. Inevitably, however, the aim of such books is persuasive and pedagogic; a concept of science drawn from them is no more likely to fit the enterprise that produced them than an image of a national culture drawn from a tourist brochure or a language text. This essay attempts to show that we have been misled by them in fundamental ways. Its aim is a sketch of the quite different concept of science that can emerge from the historical record of the research activity itself.

Even from history, however, that new concept will not be forthcoming if historical data continue to be sought and scrutinized mainly to answer questions posed by the unhistorical stereotype drawn from science texts. Those texts have, for example, often seemed to imply that the content of science is uniquely exemplified by the observations, laws, and theories described in their pages. Almost as regularly, the same books have been read as saying that scientific methods are simply the ones illustrated by the manipulative techniques used in gathering textbook data, together with the logical operations employed when relating those data to the textbook's theoretical generalizations. The result has been a concept of science with profound implications about its nature and development.

If science is the constellation of facts, theories, and methods collected in current texts, then scientists are the men who, successfully or not, have striven to contribute one or another element to that particular constellation. Scientific development becomes the piecemeal process by which these items have been

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added, singly and in combination, to the ever growing stockpile that constitutes scientific technique and knowledge. And history of science becomes the discipline that chronicles both these successive increments and the obstacles that have inhibited their accumulation. Concerned with scientific development, the historian then appears to have two main tasks. On the one hand, he must determine by what man and at what point in time each contemporary scientific fact, law, and theory was discovered or invented. On the other, he must describe and explain the congeries of error, myth, and superstition that have inhibited the more rapid accumulation of the constituents of the modern science text. Much research has been directed to these ends, and some still is.

In recent years, however, a few historians of science have been finding it more and more difficult to fulfil the functions that the concept of development-by-accumulation assigns to them. As chroniclers of an incremental process, they discover that additional research makes it harder, not easier, to answer questions like: When was oxygen discovered? Who first conceived of energy conservation? Increasingly, a few of them suspect that these are simply the wrong sorts of questions to ask. Perhaps science does not develop by the accumulation of individual discoveries and inventions. Simultaneously, these same historians confront growing difficulties in distinguishing the "scientific" component of past observation and belief from what their predecessors had readily labeled "error" and "superstition." The more carefully they study, say, Aristotelian dynamics, phlogistic chemistry, or caloric thermodynamics, the more certain they feel that those once current views of nature were, as a whole, neither less scientific nor more the product of human idiosyncrasy than those current today. If these out-of-date beliefs are to be called myths, then myths can be produced by the same sorts of methods and held for the same sorts of reasons that now lead to scientific knowledge. If, on the other hand, they are to be called science, then science has included bodies of belief quite incompatible with the ones we hold today. Given these alternatives, the historian must choose the latter. Out-of-

date theories are not in principle unscientific because they have been discarded. That choice, however, makes it difficult to see scientific development as a process of accretion. The same historical research that displays the difficulties in isolating individual inventions and discoveries gives ground for profound doubts about the cumulative process through which these individual contributions to science were thought to have been compounded.

The result of all these doubts and difficulties is a historiographic revolution in the study of science, though one that is still in its early stages. Gradually, and often without entirely realizing they are doing so, historians of science have begun to ask new sorts of questions and to trace different, and often less than cumulative, developmental lines for the sciences. Rather than seeking the permanent contributions of an older science to our present vantage, they attempt to display the historical integrity of that science in its own time. They ask, for example, not about the relation of Galileo's views to those of modern science, but rather about the relationship between his views and those of his group, i.e., his teachers, contemporaries, and immediate successors in the sciences. Furthermore, they insist upon studying the opinions of that group and other similar ones from the viewpoint—usually very different from that of modern science—that gives those opinions the maximum internal coherence and the closest possible fit to nature. Seen through the works that result, works perhaps best exemplified in the writings of Alexandre Koyré, science does not seem altogether the same enterprise as the one discussed by writers in the older historiographic tradition. By implication, at least, these historical studies suggest the possibility of a new image of science. This essay aims to delineate that image by making explicit some of the new historiography's implications.

What aspects of science will emerge to prominence in the course of this effort? First, at least in order of presentation, is the insufficiency of methodological directives, by themselves, to dictate a unique substantive conclusion to many sorts of scientific questions. Instructed to examine electrical or chemical phe-

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nomena, the man who is ignorant of these fields but who knows what it is to be scientific may legitimately reach any one of a number of incompatible conclusions. Among those legitimate possibilities, the particular conclusions he does arrive at are probably determined by his prior experience in other fields, by the accidents of his investigation, and by his own individual makeup. What beliefs about the stars, for example, does he bring to the study of chemistry or electricity? Which of the many conceivable experiments relevant to the new field does he elect to perform first? And what aspects of the complex phenomenon that then results strike him as particularly relevant to an elucidation of the nature of chemical change or of electrical affinity? For the individual, at least, and sometimes for the scientific community as well, answers to questions like these are often essential determinants of scientific development. We shall note, for example, in Section II that the early developmental stages of most sciences have been characterized by continual competition between a number of distinct views of nature, each partially derived from, and all roughly compatible with, the dictates of scientific observation and method. What differentiated these various schools was not one or another failure of method—they were all "scientific"—but what we shall come to call their incommensurable ways of seeing the world and of practicing science in it. Observation and experience can and must drastically restrict the range of admissible scientific belief, else there would be no science. But they cannot alone determine a particular body of such belief. An apparently arbitrary element, compounded of personal and historical accident, is always a formative ingredient of the beliefs espoused by a given scientific community at a given time.

That element of arbitrariness does not, however, indicate that any scientific group could practice its trade without some set of received beliefs. Nor does it make less consequential the particular constellation to which the group, at a given time, is in fact committed. Effective research scarcely begins before a scientific community thinks it has acquired firm answers to questions like the following: What are the fundamental entities

of which the universe is composed? How do these interact with each other and with the senses? What questions may legitimately be asked about such entities and what techniques employed in seeking solutions? At least in the mature sciences, answers (or full substitutes for answers) to questions like these are firmly embedded in the educational initiation that prepares and licenses the student for professional practice. Because that education is both rigorous and rigid, these answers come to exert a deep hold on the scientific mind. That they can do so does much to account both for the peculiar efficiency of the normal research activity and for the direction in which it proceeds at any given time. When examining normal science in Sections III, IV, and V, we shall want finally to describe that research as a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education. Simultaneously, we shall wonder whether research could proceed without such boxes, whatever the element of arbitrariness in their historic origins and, occasionally, in their subsequent development.

Yet that element of arbitrariness is present, and it too has an important effect on scientific development, one which will be examined in detail in Sections VI, VII, and VIII. Normal science, the activity in which most scientists inevitably spend almost all their time, is predicated on the assumption that the scientific community knows what the world is like. Much of the success of the enterprise derives from the community's willingness to defend that assumption, if necessary at considerable cost. Normal science, for example, often suppresses fundamental novelties because they are necessarily subversive of its basic commitments. Nevertheless, so long as those commitments retain an element of the arbitrary, the very nature of normal research ensures that novelty shall not be suppressed for very long. Sometimes a normal problem, one that ought to be solvable by known rules and procedures, resists the reiterated onslaught of the ablest members of the group within whose competence it falls. On other occasions a piece of equipment designed and constructed for the purpose of normal research fails

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to perform in the anticipated manner, revealing an anomaly that cannot, despite repeated effort, be aligned with professional expectation. In these and other ways besides, normal science repeatedly goes astray. And when it does—when, that is, the profession can no longer evade anomalies that subvert the existing tradition of scientific practice—then begin the extraordinary investigations that lead the profession at last to a new set of commitments, a new basis for the practice of science. The extraordinary episodes in which that shift of professional commitments occurs are the ones known in this essay as scientific revolutions. They are the tradition-shattering complements to the tradition-bound activity of normal science.

The most obvious examples of scientific revolutions are those famous episodes in scientific development that have often been labeled revolutions before. Therefore, in Sections IX and X, where the nature of scientific revolutions is first directly scrutinized, we shall deal repeatedly with the major turning points in scientific development associated with the names of Copernicus, Newton, Lavoisier, and Einstein. More clearly than most other episodes in the history of at least the physical sciences, these display what all scientific revolutions are about. Each of them necessitated the community's rejection of one time-honored scientific theory in favor of another incompatible with it. Each produced a consequent shift in the problems available for scientific scrutiny and in the standards by which the profession determined what should count as an admissible problem or as a legitimate problem-solution. And each transformed the scientific imagination in ways that we shall ultimately need to describe as a transformation of the world within which scientific work was done. Such changes, together with the controversies that almost always accompany them, are the defining characteristics of scientific revolutions.

These characteristics emerge with particular clarity from a study of, say, the Newtonian or the chemical revolution. It is, however, a fundamental thesis of this essay that they can also be retrieved from the study of many other episodes that were not so obviously revolutionary. For the far smaller professional

group affected by them, Maxwell's equations were as revolutionary as Einstein's, and they were resisted accordingly. The invention of other new theories regularly, and appropriately, evokes the same response from some of the specialists on whose area of special competence they impinge. For these men the new theory implies a change in the rules governing the prior practice of normal science. Inevitably, therefore, it reflects upon much scientific work they have already successfully completed. That is why a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process that is seldom completed by a single man and never overnight. No wonder historians have had difficulty in dating precisely this extended process that their vocabulary impels them to view as an isolated event.

Nor are new inventions of theory the only scientific events that have revolutionary impact upon the specialists in whose domain they occur. The commitments that govern normal science specify not only what sorts of entities the universe does contain, but also, by implication, those that it does not. It follows, though the point will require extended discussion, that a discovery like that of oxygen or X-rays does not simply add one more item to the population of the scientist's world. Ultimately it has that effect, but not until the professional community has re-evaluated traditional experimental procedures, altered its conception of entities with which it has long been familiar, and, in the process, shifted the network of theory through which it deals with the world. Scientific fact and theory are not categorically separable, except perhaps within a single tradition of normal-scientific practice. That is why the unexpected discovery is not simply factual in its import and why the scientist's world is qualitatively transformed as well as quantitatively enriched by fundamental novelties of either fact or theory.

This extended conception of the nature of scientific revolutions is the one delineated in the pages that follow. Admittedly the extension strains customary usage. Nevertheless, I shall con-

of the feast raises questions which have been of infinite significance to the religious history of Europe.

Frances A. Yates,
Collected Essays vol. III,
Ideas & Ideals

Chapter Twenty-nine

THE HERMETIC TRADITION IN RENAISSANCE SCIENCE*

'IF THERE is any characteristic by which the Renaissance can be recognised it is, I believe, in the changing conception of Man's relation to the Cosmos.'[1] That is a quotation from a fairly recent book on *Science and the Renaissance*, the writer of which proceeds to inquire where we should look for the origins of a change in the climate of opinion in western Europe which could have produced this changed relation to the cosmos. He looks, naturally, first of all in the movement known as 'Renaissance Neoplatonism', originating in the renewed study of Plato and the Platonists in the Florentine circle of Marsilio Ficino, but he dismisses this movement as useless for his search. There is no evidence, he thinks, that the Florentine academicians had any but an incidental interest in the problem of knowledge of the external world or of the structure of the cosmos.[2] Yet the movement loosely known as 'Renaissance Neoplatonism' is the movement which – coming in time between the Middle Ages and the seventeenth century – ought to be the originator of the changed climate of opinion, the change in man's attitude to the cosmos, which was to be fraught with such momentous consequences. The difficulty has been, perhaps, that historians of philosophy may have somewhat misled us as to the nature of that movement. When treated as straight philosophy, Renaissance Neoplatonism may dissolve into a rather

* Published in *Art, Science and History in the Renaissance*, edited by Charles S. Singleton, Baltimore, 1967.

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vague eclecticism. But the new work done in recent years on Marsilio Ficino and his sources has demonstrated that the core of the movement was Hermetic, involving a view of the cosmos as a network of magical forces with which man can operate. The Renaissance magus had his roots in the Hermetic core of Renaissance Neoplatonism, and it is the Renaissance magus, I believe, who exemplifies that changed attitude of man to the cosmos which was the necessary preliminary to the rise of science.

The word 'Hermetic' has many connotations; it can be vaguely used as a generic term for all kinds of occult practices, or it can be used more particularly of alchemy, usually thought of as the Hermetic science *par excellence*. This loose use of the word has tended to obscure its historical meaning – and it is in the historical sense alone that I use it. I am not an occultist, nor an alchemist, nor any kind of sorceress. I am only a humble historian whose favourite pursuit is reading. In the course of this reading and reading, I came to be immensely struck by the phenomenon – to which scholars in Italy, in the United States, and in my own environment in the Warburg Institute had been drawing attention, namely the diffusion of Hermetic texts in the Renaissance.[3]

I must very briefly remind you that the first work which Ficino translated into Latin at the behest of Cosimo de' Medici was not a work of Plato's but the *Corpus Hermeticum*, the collection of treatises going under the name of 'Hermes Trismegistus'. And I must also remind you that Ficino and his contemporaries believed that 'Hermes Trismegistus' was a real person, an Egyptian priest, almost contemporary with Moses, a Gentile prophet of Christianity, and the source – or one of the sources with other *prisci theologi* – of the stream of ancient wisdom which had eventually reached Plato and the Platonists. It was mainly, I believe, in the Hermetic texts that the Renaissance found its new, or new-old, conception of man's relation to the cosmos. I illustrate this very briefly from two of the Hermetic texts.

The 'Pimander',[4] the first treatise of the *Corpus Hermeticum*, gives an account of creation which, although it seems to recall Genesis, with which Ficino of course compared it,[5] differs radically from Genesis in its account of the creation of man. The second creative act of the Word in the 'Pimander', after the creation of light and the elements of nature, is the creation of the heavens, or more particularly of the Seven Governors or seven planets on which the lower elemental world was believed to depend. Then followed the creation of man who 'when he saw the creation

which the demiurge had fashioned . . . wished also to produce a work, and permission to do this was given him by the Father. Having thus entered into the demiurgic sphere in which he had full power, the Governors fell in love with man, and each gave to him a part of their rule . . .'

Contrast this Hermetic Adam with the Mosaic Adam, formed out of the dust of the earth. It is true that God gave him dominion over the creatures, but when he sought to know the secrets of the divine power, to eat of the tree of knowledge, this was the sin of disobedience for which he was expelled from the Garden of Eden. The Hermetic man in the 'Pimander' also falls and can also be regenerated. But the regenerated Hermetic man regains the dominion over nature which he had in his divine origin. When he is regenerated, brought back into communion with the ruler of 'the all' through magico-religious communion with the cosmos, it is the regeneration of a being who regains his divinity. One might say that the 'Pimander' describes the creation, fall and redemption not of a man but of a magus – a being who has within him the powers of the Seven Governors and hence is in immediate and most powerful contact with elemental nature.

Here – in the Hermetic core of Ficinian Neoplatonism – there was indeed a vast change in the conception of man's relation to the cosmos. And in the Hermetic *Asclepius*,[6] the work which had been known all through the Middle Ages but which became most potently influential at the Renaissance through the respect accorded to the Egyptian Hermes Trismegistus and all his works, the magus man is shown in operation. The Egyptian priests who are the heroes of the *Asclepius* are presented as knowing how to capture the effluxes of the stars and through this magical knowledge to animate the statues of their gods. However strange his operations may seem to us, it is man the operator who is glorified in the *Asclepius*. As is now well known, it was upon the magical passages in the *Asclepius* that Ficino based the magical practices which he describes in his *De vita coelitus comparanda*.[7] And it was with a quotation from the *Asclepius* on man as a great miracle that Pico della Mirandola opened his *Oration on the Dignity of Man*. With that oration, man as magus has arrived, man with powers of operating on the cosmos through magia and through the numerical conjurations of Cabala.[8]

I believe that the tradition which has seen in Pico della Mirandola's oration and in his nine hundred theses a great turning-point in European history has not been wrong, though sometimes

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wrongly interpreted. It is not as the advocate of 'humanism' in the sense of the revival of classical studies that he should be chiefly regarded but as the spokesman for the new attitude to man in his relation to the cosmos, man as the great miracle with powers of acting on the cosmos. From the new approach to them, Ficino and Pico emerge not primarily as 'humanists', nor even primarily, I would say, as philosophers, but as magi. Ficino's operations were timid and cautious; Pico came out more boldly with the ideal of man as magus. And if, as I believe, the Renaissance magus was the immediate ancestor of the seventeenth-century scientist, then it is true that 'Neoplatonism' as interpreted by Ficino and Pico was indeed the body of thought which, intervening between the Middle Ages and the seventeenth century, prepared the way for the emergence of science.

While we may be beginning to see the outlines of a new approach to the history of science through Renaissance magic, it must be emphasized that there are enormous gaps in this history as yet – gaps waiting to be filled in by organized research. One of the most urgent needs is a modern edition of the works of Pico della Mirandola, an edition which should not be merely a reprint but which would trace the sources of, for example, the nine hundred theses. Though laborious, this would not be an impossible task, and until it is done, the historian of thought lacks the foundation from which to assess one of its most vital turning-points.

It is convenient to consult the practical compendium for a would-be magus compiled by Henry Cornelius Agrippa as a guide to the classifications of Renaissance magic.[9] Based on Ficino and the *Asclepius*, and also making use of one of Ficino's manuscript sources, the *Picatrix*,[10] and based on Pico and Reuchlin for Cabalist magic, Agrippa distributes the different types of magic under the three worlds of the Cabalists. The lowest or elemental world is the realm of natural magic, the manipulation of forces in the elemental world through the manipulation of the occult sympathies running through it. To the middle celestial world of the stars belongs what Agrippa calls mathematical magic. When a magician follows natural philosophy and mathematics and knows the middle sciences which come from them – arithmetic, music, geometry, optics, astronomy, mechanics – he can do marvellous things. There follow chapters on Pythagorean numerology and on world harmony, and on the making of talismans. To the highest or

supercelestial world belongs religious magic, and here Agrippa treats of magical rituals and of the conjuring of angels.

The magical world-view here expounded includes an operative use of number and regards mechanics as a branch of mathematical magic. The Hermetic movement thus encouraged some of the genuine applied sciences, including mechanics, which Campanella was later to classify as 'real artificial magic'.[11] Many examples could be given of the prevalent confusion of thought between magic and mechanics. John Dee, for example, branded as the 'great conjuror' for his angel-summoning magic, was equally suspect on account of the mechanical Scarabaeus which he constructed for a play at Trinity College, Cambridge.[12] In his preface to Henry Billingsley's translation of Euclid, Dee bitterly protests against the reputation for conjuring which his skill in mechanics has brought him:

> And for . . . marueilous Actes and Feates, Naturally, Mathematically, and Mechanically wrought and contriued, ought any honest Student and Modest Christian Philosopher, be counted & called a Coniuror?[13]

Yet there is no doubt that for Dee his mechanical operations, wrought by number in the lower world, belonged to the same world-view as his attempted conjuring of angels by Cabalist numerology. The latter was for him the highest and most religious use of number, the operating with number in the supercelestial world.

Thus the strange mental framework outlined in Agrippa's *De occulta philosophia* encouraged within its purview the growth of those mathematical and mechanical sciences which were to triumph in the seventeenth century. Of course it was through the recovery of ancient scientific texts, and particularly of Archimedes, that the advance was fostered, but even here the Hermetic outlook may have played a part which has not yet been examined. Egypt was believed to have been the home of mathematical and mechanical sciences. The cult of Egypt, and of its great soothsayer, Hermes Trismegistus, may have helped to direct enthusiastic attention toward newly recovered scientific texts. I can only give one example of this.

In 1589 there was published in Venice a large volume by Fabio Paolini entitled *Hebdomades*. D. P. Walker has said of this work that it contains 'not only the theory of Ficino's magic but also the

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whole complex of theories of which it is a part: the Neo-Platonic cosmology and astrology on which magic is based, the *prisca theologia* and *magia*'[14] and so on. It represents the importation of the Florentine movement into Venice and into the discussions of the Venetian academies. The movement has not yet been adequately studied in its Venetian phase, in which it underwent new developments. When speaking of the magical statues of the Hermetic *Asclepius*, Paolini makes this remark: 'we may refer these to the mechanical art and to those machines which the Greeks call *automata*, of which Hero has written.'[15] Paolini is here speaking in the same breath of the statues described by Hermes Trismegistus in the *Asclepius*, which the Egyptian magicians knew how to animate, and of the work on automata by Hero of Alexandria which expounds mechanical or pneumatic devices for making statues move and speak in theatres or temples. Nor is he intending to debunk the magic statues of the *Asclepius* by showing them up as mere mechanisms, for he goes on to speak with respect of how the Egyptians, as described by Trismegistus, knew how to compound their statues out of certain world materials and to draw into them the souls of demons. There is a basic confusion in his mind between mechanics as magic and magic as mechanics, which leads him to a fascinated interest in the technology of Hero of Alexandria. Such associations may also account for passages in the *Hebdomades*, to which Walker has drawn attention, in which Paolini states that the production of motion in hard recalcitrant materials is not done without the help of the *anima mundi*, to which he attributes, for example, the invention of clocks.[16] Thus even the clock, which was to become the supreme symbol of the mechanistic universe established in the first phase of the scientific revolution, had been integrated into the animistic universe of the Renaissance, with its magical interpretations of mechanics.

Among the great figures of the Renaissance who have been hailed as initiators of modern science, one of the greatest is Leonardo da Vinci. We are all familiar with the traditional reputation of Leonardo as a precursor, throwing off the authority both of the schools and of rhetorical humanism, to which he opposed concrete experiment integrated with mathematics. In two essays on Leonardo, Professor Eugenio Garin argues, with his usual subtlety, that Vasari's presentation of the great artist as a magus, a 'divine' man, may be nearer the truth.[17] Garin points to Leonardo's citation of 'Hermes the philosopher' and to his definition

of force as a spiritual essence. According to Garin, Leonardo's conception of spiritual force 'has little to do with rational mechanics but has a very close relationship to the Ficinian-Hermetic theme of universal life and animation'.[18] If, as Garin seems to suggest, it is after all within the Renaissance Hermetic tradition that Leonardo should be placed, if he is a 'divine' artist whose strong technical bent is not unmixed with magic and theurgy, whose mechanics and mathematics have behind them the animist conception of the universe, this would in no way diminish his stature as a man of genius. We have to get rid of the idea that the detection of Hermetic influences in a great Renaissance figure is derogatory to the figure. Leonardo's extraordinary achievements would be, on the hypothesis put forward by Garin, one more proof of the potency of the Hermetic impulses toward a new vision of the world, one more demonstration that the Hermetic core of Renaissance Neoplatonism was the generator of a movement of which the great Renaissance magi represent the first stage.

In the case of John Dee, we do not have to get rid of a reputation for enlightened scientific advance, built up by nineteenth-century admirers, in order to detect the Hermetic philosopher behind the scientist. Dee's reputation has not been at all of a kind to attract the enlightened. The publication in 1659 of Dee's spiritual diaries, with their strange accounts of conferences with the spirits supposedly raised by Dee and Kelley in their conjuring operations, ensured that it was as a conjuror, necromancer, or deluded charlatan of the most horrific kind that Dee's reputation should go down to posterity. Throughout the nineteenth century this image of Dee prevailed, and it warned off those in search of precursors of scientific enlightenment from examining Dee's other works. Though Dee's reputation as a genuine scientist and mathematician has been gradually growing during the present century, some survival of the traditional prejudice against him may still account for the extraordinary fact that Dee's preface to Billingsley's translation of Euclid (1570), in which he fervently urges the extension and encouragement of mathematical studies, was not reprinted until 1975. While I suppose that practically every educated person either possesses one of the many modern editions of Francis Bacon's *Advancement of Learning* or has had easy access to them in some library, Dee's mathematical preface could, until then, be read only in the rare early editions of the Euclid. Yet Dee's preface is in English, like Bacon's *Advancement*, and in a nervous and original kind of English; and as a manifesto for the advancement

of science it is greatly superior to Bacon's work. For Dee most strongly emphasizes the central importance of mathematics, while the neglect or relative depreciation of mathematics is, as we all know, the fatal blind spot in Bacon's outlook and the chief reason why his inductive method did not lead to scientifically valuable results.

It is not for me here to go through the mathematics of the preface nor to discuss Dee's work as a genuine scientist and mathematician, consulted by technicians and navigators. The work done on these matters by E. G. R. Taylor[19] and F. R. Johnson[20] is well known, and there is a remarkable thesis on Dee by I. R. F. Calder[21] which is unfortunately still unpublished. My object is solely to emphasize the context of Dee's mathematical studies within the Renaissance tradition which we are studying. That Dee goes back to the great Florentine movement for his inspiration is suggested by the fact that he appeals, in his plea for mathematics, to the 'noble Earle of Mirandula' and quotes from Pico's nine hundred theses the statement in the eleventh mathematical conclusion that 'by numbers, a way is to be had to the searching out and understanding of euery thyng, hable to be knowen'.[22] And it was certainly from Agrippa's compilation with its classification of magical practices under the three worlds that he drew the discussion of number in the three worlds with which the preface opens. It may be noticed, too, that it is with those mathematical sciences which Agrippa classifies as belonging to the middle celestial world that the preface chiefly deals,[23] though there are many other influences in the preface, particularly an important influence of Vitruvius. This may raise in our minds the curious thought that it was *because*, unlike Francis Bacon, he was an astrologer and a conjuror, attempting to put into practice the full Renaissance tradition of Magia and Cabala as expounded by Agrippa, that Dee, unlike Bacon, was imbued with the importance of mathematics.

I should like to try to persuade sensible people and sensible historians to use the word *Rosicrucian*. This word has bad associations owing to the uncritical assertions of occultists concerning the existence of a secret society or sect calling themselves Rosicrucians, the history and membership of which they claim to establish. Though it is important that the arguments for and against the existence of a Rosicrucian society should be carefully and critically sifted, I should like to be able to use the word here without raising the secret-society question at all. The word *baroque* is used, rather vaguely, of a certain style of sensibility

and expression in art without in the least implying that there were secret societies of baroquists, secretly propagating baroque attitudes. In a similar way the word *Rosicrucian* could, I suggest, be used of a certain style of thinking which is historically recognizable without raising the question of whether a Rosicrucian style of thinker belonged to a secret society.

It would be valuable if the word could be used in this way, as it might then come to designate a phase in the history of the Hermetic tradition in relation to science. A very generalized attempt to define two such phases might run somewhat on the following lines. The Renaissance magus is very closely in touch with artistic expression; the talisman borders in this period on painting and sculpture; the incantation is allied to poetry and music. The Rosicrucian type, though not out of touch with such attitudes, tends to develop more in the direction of science, mixed with magic. Thus though the Rosicrucian type comes straight out of the Renaissance Hermetic tradition, like the earlier magi, he may orientate it in slightly different directions or put the emphasis rather differently. The influx of Paracelsan alchemy and medicine, itself originally stimulated by Ficinian influences, is important for the latter or Rosicrucian type, who is often, perhaps always, strongly influenced by Paracelsus. The tradition in its later or Rosicrucian phase begins to become imbued with philanthropic aims, possibly as a result of Paracelsan influence. Finally, the situation of the Rosicrucian in society is worse and more dangerous than that of the earlier magi. There were always dangers, which Ficino timidly tried to avoid and from which Pico della Mirandola did not escape. But as a result of the worsening political and religious situation in Europe, and of the strong reactions against magic in both Catholic and Protestant countries, the Rosicrucian seems a more hunted being than the earlier magi, some of whom seem able to expand quite happily in the atmosphere of the early Renaissance Neoplatonism, feeling themselves in tune with the age. The artist Leonardo or the poet Ronsard might be examples of such relatively happy expansion of great figures who are not untinctured with the Hermetic core of Neoplatonism. The Rosicrucian, on the other hand, tends to have persecution mania. Though usually of an intensely religious temper, he avoids identifying himself with any of the religious parties and hence is suspected as an atheist by them all, while his reputation as a magician inspires fear and hatred. Whether or not he belongs to a secret society, the Rosicrucian is a secretive type, and has to be.