1

ACCOUNTS OF THE RISE OF EARLY MODERN SCIENCE

Introduction

In 1948 Herbert Butterfield coined the term "scientific revolution," to upgrade the significance of the intellectual events of the sixteenth and seventeenth centuries and thus change the face of European historiography. He considers this revolution to have:

> overturned the authority in science not only of the middle ages but of the ancient world—since it ended not only in the eclipse of scholastic philosophy but in the destruction of Aristotelian physics—it outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes, mere internal displacements within the system of medieval Christendom. Since it changed the character of men's habitual mental operations even in the conduct of the non-material sciences, while transforming the whole diagram of the physical universe and the very texture of human life itself, it looms so large as the real origin both of the modern world and of the modern mentality that our customary periodization of European history has become an anachronism and an encumbrance. (1968:vii)

Perhaps this rather grandiose estimation of the causal significance of the scientific revolution results from a failure to entertain the possibility of reciprocal effect between science and the results mentioned. Indeed, it is our argument that Butterfield has reversed the direction of some of the important influences. The texture of everyday life, we suggest, also affects scientific thought. It helps to "transform the very texture of human life" because it resides and is nurtured there. The "scientific revolution" remains, nonetheless, an indicator of truly significant changes.

The special status accorded science in Butterfield's account is, in some ways, a justification of science's self-understanding. Much of the historical scholarship from Butterfield through the 1960s represents, in part, a defense of this self-understanding against irrationalism and also against Marxist attempts to relate at least some features of science to class structure and other social conditions. Within this body of scholarship, however, there is a competing array of factors, developments and conditions vying for top spot as the reason for the emergence of such a successful world-view. With reference to the recovery and refinement of Greek sources alone, the Pythagoreans, Plato, Aristotle, Archimedes, the pre-Socratics, atomists and artisans are cited. Other factors include early modern artisanry, developments in commercial reckoning, experimental method, the overthrow of theology, institutional and economic supports and Islamic algebra. All may very well have played their part in various ways at different times in a highly nuanced story stretching over 500 years.

We shall examine a few exemplars of this post World War II scholarship in order to outline the main factors cited as responsible for the rise of modern science. We present this material in rather cursory outline in order simply to identify the main factors and lines of argument because we do not so much take issue with the factors cited as indicate, after discussion of the Marxist tradition, what remains unaccounted for. This will then help us to refine and focus our own line of inquiry.

Post–World War II Accounts of the Rise of Science

Various commentators disagree on the essential factors most responsible for the development of modern science, but are virtually unanimous as to precisely what it was that developed. Although Hooykaas (1987:454–5) notes that the analyst's interpretation of the rise of science depends in some measure on whether one adopts an "evolutionistic" or "phenomenological" historiography (the former emphasizing the cumulative and progressive character of science and the latter the experiential richness of contemporary milieux and paradigms), he nonetheless characterizes modern science unproblematically as (1) acknowledging no authority other than the data of nature; (2) employing art in experiment; (3) favouring a mechanistic world-picture, rather than, for example, the organistic one of the ancients; and (4) quantifying qualities and describing and explaining phenomena in mathematical terms. For his own part, Hooykaas cites theological voluntarism, mechanistic conceptions, free manual labour and experiment, and respect for "experience" as the most important factors (1987:456).

Hooykaas (1987:461) attributes the triumph of mechanism to the closer contact between engineers and artisans, on the one hand, and scholars on the other, in the sixteenth and seventeenth centuries. The mixture, in the same or closely associated figures, of experience and learning resulted from and contributed to a respect for direct experience of nature. The machine analogy and its mathematical treatment, however, receive scant attention in Hooykaas' analysis.

He concludes (1987:471) by boiling down to two the major causes of the development of modern science:

> firstly, the new natural history and the methodological epistemological changes connected with it; and secondly, the transition from an organistic to a mechanistic view of the world, a change closely connected with experimental philosophy and the contribution made to it by engineers, physicians, alchemists, cartographers, pilots and instrumentmakers.

Mathematization, while important in Hooykaas' scheme, receives little attention.

Richard Olson (1982:214–15) concurs, for the most part, with Hooykaas' focus on the contact between scholars and engineers/artists. Olson refers to this development as the "democratization of science." While Olson (1982:217–24) recognizes the contribution of mathematics to this Renaissance phenomenon, he does not describe or explain the development of this mathematics, preferring instead to outline its incorporation into perspective and engineering.

For Ludwig Edelstein (1957:93), although the Greeks displayed experimentalism, rationalism and the use of mathematics, "the impression that ancient science is modern in character is bought at the price of neglecting or omitting all the evidence to the contrary." The atomist and craft traditions are excluded as factors on the basis of their inspiration in irrational analogies (1957:105). Thales, Anaximander, Anaximenes, Heraclitus, Empedocles, Epicurus and even Archimedes, Geminus and Pappus are excluded on these grounds. Those worthy of inclusion, in Edelstein's view, are the Aristotelians, Platonists and Stoics because their efforts were later wedded, through Roman political unification and the establishment of state-supported academies, to an interest in the technical harnessing of natural forces. Edelstein (1957:115) concludes that society was indifferent to "science" in this early period. The esteem accorded Classical and Hellenistic science is, for him, a modern gloss.

A. C. Crombie (1957) claims that modern science was born of the marriage of Aristotle with a new technology which had been growing since the middle ages. Aristotle's logic, along with Greek and Arabic mathematics, joined with technique to bring about a transition from a metaphysical to a mathematical-physical interpretation of nature. Modern science represents a reunion of Aristotle, Plato and Archimedes, on the one hand, with the new artisanry, on the other (1953:292–3). In regard to artisanry, he cites Vives's recommendation to study the arts of cooking, building, navigation, agriculture and clothmaking (1953:132). Furthermore, "it took a scholar to write about arithmetic, yet most of the advances that followed Fibonacci's treatise on the Hindu numerals were made in the interest of commerce" (1953:129).

Logic and rationalism were introduced through Aristotle, the geometric conception of the ultimate form of things through Plato, and the more strictly mathematical treatment through Euclid and Archimedes (1957:131; 1953:292). Even Archimedes, however, made no actual measurements of real quantities (1953:135). The ingredients comprising modern science for Crombie are Aristotle, Plato, Euclid, Archimedes and the Paris Ockhamites, but commercial and industrial developments were responsible for the emphasis on measurement.

According to J. H. Randall, the reconstruction of Aristotle's physics in the light of his logic through the mechanical and mathematical problems of the Galilean Age "led to the precise formulation of the method and structure of science acclaimed by all the seventeenth century scientists" (1957:142). The Oxford Mertonians and Paris Ockhamites thus engaged in a revision of Aristotle from within an Aristotelian framework, which resulted eventually in the experimental school at Padua. Nicholas of Cusa, Puerbach, Regiomontanus and Copernicus all studied at Padua (1957:146). The marriage of this "critical Aristotelianism" with a this-worldly commercial culture was largely responsible for the scientific revolution (1957:145–6).

Alexandre Koyré decides heavily in favour of Plato and Archimedes as progenitors of the scientific revolution, and against

Aristotle and social conditions (1957:145–6). The key for modern science, claims Koyré, was a mathematical approach to Being as represented in Galileo's mathematization of nature, and it is this emphasis that signifies the primary contribution of Platonism. Sheer observation would have led in false directions; mathematical natural science results in many anti–common-sense developments (1978:149–52). If mathematics is key and observation secondary, you are a Platonist; if the reverse is the case, you are an Aristotelian (1978:168).

Marie Boas focusses on the recovery of ancient atomism, which paved the way for the notion of corpuscularity in the mechanical philosophy of thinkers such as Robert Boyle (1952:143). The recovery of atomism, she claims, succeeded in banishing the Aristotelian substantial forms and real qualities (1952:415–18), while the Platonic-Pythagorean emphasis on number and form allowed the application of mathematics to mechanics (1962:86–7).

While Aristotelians held that the properties of a body resulted from "real qualities" and "substantial forms," for Democritus, the size and shape of atoms were responsible for those properties. "A true mechanical philosophy, however, required the introduction of another concept, the concept that the motion of the particles might affect the properties of the matter they composed" (1952:521).

Butterfield, like Koyré, claims that the scientific revolution is the result of new ideas rather than new observations. The mathematical conception of motion, according to Butterfield, remained the biggest intellectual hurdle for the Aristotelian theory of motion for 1500 years (1968:1–4). The most significant part of this transition is the change from impetus theories of motion to those of Galileo, and the key for this development was the translation (especially those of 1543) of Euclid and Archimedes. Thereafter, the tendency to mathematize problems grew rapidly (1968:13–15). Western science was able to develop in this way, since the sacking of Constantinople in 1453 left Europe with the Greek legacy, which, coupled with "a complicated set of conditions which existed only in western Europe" (1968:175–77), fostered the rapid growth of science.

For Stephen F. Mason, a set of early modern social and intellectual conditions allowed for craft and intellectual traditions to merge in a political and religious context in which Protestant modernity and universalism were winning out over Catholic

Thomism and Aristotelianism. As far as the craft heritage is concerned, Mason mentions the contributions of Pierre de Maricourt, Agricola, and Robert Norman (1962:140). Craftsmen from de Maricourt to Norman, however, needed scholars to develop a scientific theory of magnetism (1962:147).

Key in this scholarship is the development of mathematics, and Mason suggests that, while there are continuities from Greek to modern mathematics, the modern is different from the Greek in essential respects (1962:148). Beginning in northern Italy in the late fifteenth and sixteenth centuries, da Vinci, Tartaglia, Cardano, Benedetti and Stevin developed experimental and mathematical mechanics. (Tartaglia and Stevin were also both bookkeepers [1962:149–50]).

Galileo established the mathematization of nature and was thus heir to the craft-scholar merger; Descartes generalized the mathematical method and constructed a mechanical model of nature (1962:165–8). Descartes made geometry algebraic, following the efforts of Viète and Harriot (1962:168–9). "For Descartes the physical and organic world was a homogeneous, mechanical system composed of qualitatively similar entities, each following the quantitative mechanical laws revealed by the analysis of the mathematical method" (1962:171).

Cosmological and theological elements of the old world-view came under attack from scientists and Protestant reformers, and on occasion these roles were combined in the same person. The attacks ultimately resulted in the unification of coelestial and terrestrial physics and the decline of the doctrine that different substances possessed different forms or qualities (1962:171).

According to Hugh Kearney, the rise of modern science resulted from the fusion of conflicting Greek traditions in the complicated social conditions and religious struggles of early modern Europe.

> The conflicting heritage of Greek thought created a challenge for western thinkers. It also led to immense intellectual confusion, which was intensified by the Reformation and the struggles of sixteenth century Europe when religious orthodoxies struggled for dominance. From this the history of science was not immune. Science did not develop in a separate compartment labelled "The Scientific Revolution," but was itself part of the process of social and intellectual change. The rise of mathematics and the development of experimental

> method took place in a world where religion and science (or natural philosophy as it was then termed) were not distinct activities as they are in the West today. (1971:14)

Under such conditions, Kearney claims, the organic, magical and mechanistic traditions merged to form modern science. There was no direct line of progression; the truth did not "slowly broaden down from precedent to precedent" (1971:22).

The organic tradition explains nature by means of analogies which are primarily biological. Aristotle is the prime representative of this school. The magical tradition views nature as art. This esoteric knowledge is represented in the writings of the mythical figure, Hermes Trismegistus, but influenced others such as Kepler, Newton and van Helmont. The mechanistic tradition is exemplified by the work of Mersenne, Hobbes and Descartes. The legacy here is Archimedian and the analogy employed is that of the machine (1971:47–8).

A. Rupert Hall views modern science as arising in the seventeenth and eighteenth centuries as the result, in small measure, of previous attempts at experimental method, but primarily from the advent of reason as exemplified in the ideas of individual, early modern virtuosos (1954:xi). Early experimentors such as Robert Grosseteste and Roger Bacon are seen as providing only a hint at a scientific methodology (1954:7). Hall claims that intelligent civilization is no more than 400 years older than the scientific revolution which culminated from the merger of late medieval experimentalism and the revaluation of Greek geometry and Islamic algebra (1954:9). A new vision of the order of nature emerged owing to a new system of ideas, acceptable by force of their reasonability and predictive validity (1954:32–3).

These post–World War II accounts of the scientific revolution ascribe the establishment of a new world-view to various intellectual legacies and, in some cases, to a union of one or more of these with craft experience. The debates between them concern the relative importance of one or the other tradition. All are pretty much agreed on what it was that developed. We shall not contend this issue with them. Suffice it to say that we think there is good reason to ascribe *some* significance to all of the factors cited.

What developed, above all, was a mathematical mechanics. For this we require a mathematics capable of ordering the relations between qualitatively similar bodies. Although there was some disagreement as to the precise ingredients and developments in this mathematics, most would generally agree that a Pythagorean-Platonic interest in formal order was given greater specificity in the language of proportion of Euclid and Archimedes, which, through the Islamic algebraic tradition, was nurtured and transformed in late medieval and early modern Europe and ultimately formalized and established in the work of Stevin, Viète, Harriot and Descartes.

Meanwhile, an Aristotelian interest in the empirical, while not fitting well with the newer mechanism, is refined and criticized from Philoponos through the Arabo-Latin tradition of the Middle Ages and the Oxford Mertonians and Paris Ockhamites, until finally transformed and wedded to the newer mathematical concerns in the work of the sixteenth century Italians and Galileo.

Artisanry is also accorded a role in the empirical and measurement aspects of the new science. Mechanics, mathematical or otherwise, required direct experience of objects in motion and this, claim many of our exemplars, was provided by a host of less scholarly and more practically oriented thinkers in various arts and trades. The observations, "experiments" and technical innovations of various artisans from de Maricourt to Biringuccio to Norman are cited as providing the empirical material for mathematical treatment, thus completing the story of mathematical mechanics in the early modern period.

This, however, leaves two fundamental questions: (1) Exactly how and why was mathematics transformed and refined to enable it to mathematize mechanics? (2) How do artisanal observations develop into the appropriate concepts for such a mathematical mechanics? The first question we shall leave to our more detailed analysis in Chapters 3 and 4. The second has been the province of primarily Marxist historians of science and we shall turn now to a discussion of these *praxis* thinkers.

Marxism, Praxis and Science

Although Marxist analysts of the history of science are concerned with praxis, this tends to be understood as technology in the narrow sense. Science, technology and economic necessity are viewed as objectively based on the properties of things. Frederick Engels (to Borgius, 25 January 1894, from Kuruma 1977: 144–5) suggests that science and technology are mutually dependent.

> If technology, as you say, is for the most part dependent on the state of science, then this is even more so on the *state* and needs of technology. If society has a technological require-

> ment, this helps science more than ten universities. The whole of hydrostatics (Torrecelli etc.) was summoned up by the need to regulate the mountain rivers of Italy in the sixteenth and seventeenth centuries. We only know something rational about electricity since the time of its technical applicability. In Germany, however, one has become accustomed to writing the history of science as though it had fallen from heaven.

Engels has been criticized somewhat for such commentary as this in his *Anti-Dühring* (1962) and *Dialectics of Nature* (1940). According to Rose and Rose (1976:13), Engels himself has replaced human praxis with a "metaphysic of nature." While this is arguably the case for at least a part of Engels' work, many (both those who approve of the "metaphysic" and those who do not) would do well to consider further the context in which Engels places this commentary. He continues the above passage:

> We view economic conditions as those which condition societal development in the last instance. But the race is itself an economic factor. Now there are two points here not to be overlooked:
>
> a) The political, legal (*rechtliche*), philosophical, religious, literary, artistic etc. development harks back to the economic. But they all react on one another and on the economic basis. It is not that the economic situation is cause, alone active and everything else is only passive effect. Rather there is a reciprocal effect (*Wechselwirkung*) on the basis of thoroughgoing economic necessity *in the last instance* ....
>
> b) Thus it is not, as one might now and then pleasantly imagine, an automatic effect of economic situation, but rather people make their own history, but in a given conditioning milieu, on the basis of previous factual relations (*Verhältnisse*), among which the economic, even though influenced by the remaining political and ideological ones, are however in the last instance the decisive and pervasive ones which alone create the red thread which leads to understanding. (Engels 1977:145–6)

Other Marxist thinkers have continued Engels' line of analysis. George D. Thomson (1955) sees scientific ideas as having social origins but chooses to see correct scientific ideas in particular as having an origin in technique, and alienated, abstract thought as fetishized, as the beginning of a feudal suppression of correct, mechanical ideas. The Milesian, Thales, was the first known proponent of the notion of a self-regulating nature. For Thomson, pre-Socratic truth was compromised under feudalism, and even before that by Plato's and Aristotle's abstraction, finally to be recovered after a long struggle against feudalism. We have, thus, a sociology of error, but no analysis of how mechanical *truth* is produced.

Benjamin Farrington is concerned to outline the positive contribution of early technique to scientific thought. In order to claim roots in the pre-Socratics, Aristotle distorts their meaning, claims Farrington. Their origin was much more in the realm of technique than Aristotle will allow, and

> in Egypt and Babylon the control over nature exercised in the techniques threw little light on the processes of nature as a whole. Practice did not pass beyond the domain of practice. The domain of nature was already occupied by mythology. Mythology and technology constituted two entirely different fields of knowledge. With the Milesians technology drove mythology off the field. The central illumination of the Milesians was the notion that the whole universe works in the same way as the little bits of it that are under man's control. (Farrington 1947:3)

In the figures of Parmenides, Socrates and Plato, however, these early advances began to be opposed.

> Plato was born in the year Anaxagoras is supposed to have died. In the interval that separated the two men the attitude of Athens to Ionian science had become more clearly defined and the antagonism had deepened. It was not only that Socrates had begun his powerful movement of revolt against Ionian materialism; the technique of government through religion was also better understood as well as the threat to this technique inherent in the spread of Ionian rationalism. (Farrington 1939:87)

For J. D. Bernal, "it was the condition of the rise of capitalism that made that of experimental science possible and necessary" (1954:252). His prognosis is that science's productivity results in making capitalism unnecessary.

The edifice inherited from the Greeks was overthrown, claims Bernal. Although the Renaissance partly bridged the gap between theory and praxis, the rendering of a new science from the old was accomplished by a new set of revolutionaries, the bourgeoisie. During the Renaissance and Reformation there was a movement toward the buying and selling of commodities and labour and away from hereditary status, which movement led at a later date to a heightened conflict between ancients and moderns (1954:258, 347). A new respect was now won for artists and artisans, since they were now essential to the making as well as the spending of money.

Great developments were produced in the areas of perspective and engineering. Speaking of the work of Copernicus and Vesalius he states: "They were the first pictures of how the heavenly spheres or the human body would appear to those who had eyes clear enough to see for themselves and not through the spectacles of ancient authority" (1954:262). In a similar vein he sees the dispute about Galileo's work as one of science versus religious dogma, views the Middle Ages as barbarous and sees in the development of science a continuous erosion of the power of idealism (1954:346–7).

Edgar Zilsel (1957a) addresses the question of just how contemporaries were able to "see for themselves" and, in doing so, concurs with Crombie, Mason, Olson and Hooykaas in suggesting that modern science did not appear "before the way of thinking of the craftsmen was adopted by academically trained scholars of the upper class" (1957b:280; also 1957a:245). Zilsel attributes this development, in broad outline, to "modern technology and modern economy" (1957a:228).

In this formulation, Gilbert's scientific method and results, for example, derive primarily from the work of Robert Norman and, in a more remote way, even from Pierre de Maricourt (fl.1269). "When the seamen of the sixteenth century went to sea, they laid the foundation of the British Empire and when they retired and made compasses, of modern experimental science" (1957a:241).

For Zilsel, the development of early capitalism from the thirteenth to fifteenth centuries and the attendant growth of towns freed manual labour so that, by the time of the decay of the guilds, superior craftsmen became "free artists," from whose ranks the artist/engineers appeared (1941:54–55). These people still performed the manual work required for experiment and eventually acquired the scholarly training required for scientific thought.

> Gradually, however, the technological revolution transformed society and thinking to such a degree that the social barrier

> between liberal and mechanical arts began to crumble, and the experimental techniques of the craftsmen were admitted to the ranks of the university scholars. This was accomplished about 1600 with Galileo Galilei, Francis Bacon, and William Gilbert. One of the greatest events of the history of mankind had taken place (1941:57).

Elsewhere (1942:547), Zilsel argues the existence of similar connections to the ones we wish to illustrate, namely, between the commercially inspired work of Recorde and Digges, Pacioli and Tartaglia, and the new mathematical appropriation of nature in the sixteenth century. The innovation introduced into mathematics by the above figures and others is ignored. "Classical mathematical tradition (Euclid, Archimedes, Apollonius, Diophantus) could be revived in the sixteenth century because the new society had grown to demand calculation and measurement." While this is certainly not wrong, as far as it goes, ancient mathematical tradition is here seen to embody a universal rationality. Struik (1942:60–64), however, suggests how one might inquire into the relation between commerce and mathematical development; we follow some of his initial guidelines here.

The classical presentation of the position of "dialectical materialism" on the development of science is that of Boris Hessen (1931). In an explanation of the roots of Newton's *Principia*, Hessen accords an unscientific status to the parts of Newton's conceptual scheme of which he disapproves, and ascribes them to a social source—Newton's class position—which

> explains why those materialistic germs which were hidden in the "principia" did not grow in Newton into a fully formed structure of mechanical materialism,... but intermingled with his idealistic and theological beliefs, which, in philosophical questions, even subordinated the material elements of Newton's Physics. (Hessen 1931:183)

Truth production, however, receives a different account. In each epoch, the productive, economic need of the dominant class gives rise to a set of technical problems which require and receive expert attention. Productive forces begin a particular development which leads, in turn, to further development of those forces. Technical problems in communication, navigation, mining and ballistics lead directly to the study of the physical bases of these problems. The resulting science is seen, by Hessen, to be the result of unfettered examination of such problems and bases (1931:155–75).

Newton's class position, however, fettered the further development of mechanics. Owing to his class position, Newton saw matter as completely inert, needing to be moved from "outside"; thus he neglected other forms of motion than the mechanical, failed to develop a notion of the law of conservation of energy and viewed space as God's "sensorium" (1931:190).

The development of more advanced notions of forms of motion, claims Hessen, is predicated on the development of forces of production. With large-scale industry, technology plays a role in the increase in absolute and relative surplus value, and is predicated on the development of detail labour and a new definition of the machine in modern industry as performing a complete transformation in the material of the product (1931:195–7). Subsequent to this development, the technical rationalization of the use of the steam engine made further study of physical processes necessary and led to the working out of thermodynamics from Watt to Carnot (1931:198–9).

Although we have no quarrel with the notion that forces of production provide the occasion and impetus for attending certain problems and questions, the specific ways in which these are solved and answered (except for errors in doing so) are seen by Hessen as utterly unproblematic and in need of no explanation at all. Science, in this regard, has no history, for Hessen. Once a problem is singled out for investigation, it appears, a universal logic takes over and yields answers characterizable as objective pictures of nature and its properties.

The assumption of this universal logic enables Hessen to assume an inexorable pattern to history; he tells us, for example, what Newton lacked (1931:203). Whig history proves adaptable to the requirements of dialectical materialism. Hessen does raise the spectre of fetishism in connection with a naturalistic view of the romantic critique of the technology of his day. This view, he claims, ignores the role of *relations* of production. Hessen himself, however, for the most part, associates the origin of science with "the *methods* of production" (1931:209, 211 emphasis added).

More recently, Alfred Sohn-Rethel (1978) has taken up this same problem, but in a way which attends the social division of labour and the commodity abstraction. Sohn-Rethel still, nonetheless, views the content of the knowledge of nature as socially uninfluenced and as unproblematic since only the form, and not the content, of scientific knowledge is affected by the commodity abstraction.

Sohn-Rethel states:

> The economic concept of value resulting from [the commodity abstraction] is characterized by a complete absence of quality, a differentiation purely by quantity and by applicability to every kind of commodity and service which can occur on the market. (1978:20)

This concept and this abstraction bear, he claims, a "striking similarity with fundamental categories of quantifying natural science." About the character and source of these abstractions and concepts he writes:

> While the concepts of modern science are thought abstractions, the economic concept of value is a real one. It exists nowhere other than in the human mind but it does not spring from it. Rather it is purely social in character, arising in the spatio-temporal sphere of human interrelations. It is not people who originate these abstractions but their actions. (1978:20)

After suggesting, however, that the abstractions and concepts he is analyzing do not spring from the mind but from social relations, he proceeds to give both mind and conceptions of nature an autonomy and natural foundation which contradict his notion of their social rootedness. The argument, briefly, is as follows. In exchange, thought and action are separated. Action on the market abstracts from the natural qualities of the objects exchanged. In exchange, use is banished from the activity but not from the mind (1978:25–6); thus, there appears an independent intellect left on its own to contemplate use, that is, the physical character of the world. The abstractness of the activity is not accessible owing to the business at hand of exchange and the desirability of the commodity sought. Thus, exchange activity for Sohn-Rethel (1978:27, 75) mitigates an interpretation of nature based on any direct perception or appropriation of nature through manual labour.

Abstract social relations produce an independent intellect which, in Greek society based on slave-labour gives rise to philosophy, and in European society based on wage-labour gives rise to modern science (1978:28). This independent intellect, the mind, receives its formal elements from the commodity abstraction, and provides the foundations for both Greek philosophy and modern science. In the case of modern science, its categories differ from Greek philosophy in as much as they are required to effect a measure of control over a labour-process peopled with essentially equal beings, beings with human qualities. The ideal abstraction provides the form of thought but not the content (1978:118).

> These contents are nothing but the basic features of the physical act of commodity transfer between private owners. It is this physical event which is abstract (precisely why we have called it the 'real abstraction'). It is a compound of the most fundamental elements of nature such as space, time, matter, movement, quantity and so on. The concepts which result from the identification of these elements are thus in their origin concepts of nature. (1978:70)

Sohn-Rethel thus views the basic categories of classical mechanics as directly appropriated and unproblematic.

He marks mathematics as the dividing line between intellectual and manual labour (1978:101), but provides no account of the possible root of changes in mathematics with the rise of commodity exchange and modern mechanics. He cites the rise of coinage in ancient Greece as marking the beginning of theoretical mathematics and, although we may be in broad agreement here, Sohn-Rethel does little to analyze its content beyond remarking that it amounts to a "generalization" from monetary commensuration (1978:102). He remarks that the Renaissance craftsmen needed mathematics for controlling a new social environment technologically, but provides no account of how the new concepts of this mathematics were derived (1978:112).

Generally, for Sohn-Rethel, the form of thought is considered social, the content natural. Only the formal, abstract character of scientific thought is viewed with reference to social, historical specification. By implication, form and content are seen as independent.

> Commodity exchange, when attaining the level of a monetary economy, gives rise to the historical formation of abstract cognitive concepts able to implement an understanding of abstract primary nature from sources other than manual labour. It seems paradoxical, but is nevertheless true, that one has first to recognize the non-empirical character of these concepts before one can understand the way in which their indirect natural origin through history achieves their validation. One might speak of science as a self-encounter of nature blindly occurring in man's mind. (1978:75)

There are features, however, of the concept "mode of production" which allow a broader analysis than the Engels-to-Sohn-Rethel thesis. Franz Borkenau offers a Marxian interpretation of the rise of early modern mechanics, which attends to relations of production as much as to forces. His attention to the growth of the division of labour, as opposed simply to growth of or changes in economic need, allows an account of early scientific thought which draws directly on the cornerstone of Marx's thought, the labour theory of value.

Several advantages over more orthodox Marxist accounts accrue from Borkenau's treatment: (1) The question can be addressed of just *how*, and with which frameworks, observation can provide material for a mathematical mechanics; (2) the way in which the mathematical ingredients were developed and made their contribution can be analyzed; (3) the relations of production, as well as forces, can be given their important role in a Marxian sociology of knowledge; (4) the labour theory of value can be employed to account for the abstraction and homogenization characteristic of the mathematical-mechanistic world-view.

Social Relations, Value and the Mechanistic Abstraction

For Borkenau (1976:3), "*The natural science of the seventeenth century does not stand in the service of industrial production,* although it wanted that since the time of Bacon." What was important for production in this period of manufacture was extension and control of handicraft. The division of labour and the then nascent parallel specialization of tasks enabled calculation for profitability. While Borkenau locates this calculability in the labour-process itself, our analysis focuses first on exchange-relations where, nonetheless, we see such calculating concern most manifest until a later date when the labour-process was more developed.

Borkenau takes his cue from Marx's (1967:368, 368fn.) suggestion that Descartes viewed the world through the eyes of the manufacture period and expected new forms of production based on the new, mechanistic thought. Descartes claimed for his philosophical methods that:

> they caused me to see that it is possible to obtain knowledge which is very useful in life and that, instead of the speculative philosophy which is taught in the schools, we may find a practical philosophy by means of which, knowing the force and the action of fire, water, air, the stars, heavens and all

> other bodies that environ us, as distinctly as we know the different crafts of our artisans, we can in the same way employ them in all those uses to which they are adapted, and thus render ourselves masters and possessors of nature. (1931:119)

The form of thought or model of the world which established itself with Descartes and others in the seventeenth century Borkenau terms "the mathematical-mechanistic world-view." He outlines its main features as follows:

> It is mechanistic insofar as every event is ultimately reduced to movements of qualitatively similar bodies and to the communication of motion within a space-time continuum—in contrast to the following period, whose physics is founded on the concept of forces acting at a distance and the re-introduction of specific qualities. It is mathematical insofar as scientificity and certainty are conferred only on the form of proof of Euclidean geometry and its derivatives and insofar as there is a tendency to express all events, conceived as the sum of communications of motion by means of a set of linear equations. (1987:109–10)

While the full-blown version of this world-view manifests a refinement and development taking place in more rarefied intellectual circles, it also bears a sedimented inheritance, we would argue, from a historically specific set of social relations and from practical and "prescientific" attempts to represent those relations for practical purposes. These relations could provide a preconception for such a world-view, for Borkenau, because they can be

> characterized by the most thoroughgoing abstraction from everything qualitative. The extreme decomposition of labour creates on the one hand an abstract, general substrate that is worked on, whose chemical and other qualities are ignored as much as possible, and which is to be considered only as raw material, as pure matter, and on the other hand, the completely unqualified laborer, who is considered only as labor power in itself, whose activity is abstract labor, pure physical movement. Galileo, the greatest classical writer on physics of the manufacture period, in his major work the *Discorsi,* treats just the laws of this abstract labor. (1987:110)

Although we shall argue that the significance of "abstract labour" for present purposes derives more from relations of exchange than from a detailed analysis of the labour-process itself, this does not at all diminish the importance of the parallel which Borkenau illustrates. Indeed, Henryk Grossmann (1935) has successfully criticized aspects of Borkenau's position, but, by following some of Grossmann's and Borkenau's suggestions, we shall demonstrate the usefulness of Marx's theory of value in formulating the connections between the abstractions and reductions in social relations of exchange in the early modern period, on the one hand, and the mathematical-mechanistic view of nature, on the other.

Borkenau's prime concern is to oppose the view that early modern natural science (philosophy) represents an objective view of outer nature once the fetters of theology are cast off (1976:v–vi).

> If the actual accomplishment of the more modern philosophy is the constitution of modern science, if its basic forms—the concept of natural law, the omnipresence of efficient causality, the mathematical conception of natural regularities—are not eternal and 'natural', but rather transitory, historically conditioned forms of thought, then one must inquire about the special historical conditions, which led to the rise of these special forms of thought. (1976:vi)

Borkenau's strategy for presenting the connections between social conditions and forms of thought is to detail some of the partisan struggles over concepts of "natural law," which helped to establish bourgeois society and its particular picture of nature. His hope is to provide a simple suggestion, which will stimulate many specialized researches (1976:x). The present inquiry is undertaken in this spirit.

He hopes to correct a particular understanding of the relation between science and technology: that technological need produced scientific views. Once established, the scientific world-view was able, since the eighteenth century, to produce technical innovation for industrial application. The *origin* of this view, however, cannot be understood in this fashion. Seventeenth-century production, states Borkenau, retained a basis in handicraft, which did not hold much promise for scientific application. Even in manufactories, let alone in the putting-out system, the key to productivity was still the dividing up of tasks. In the fifteenth and sixteenth centuries money capital exceeded the limits of guild production and increased productivity in the form of improved organization of labour (1976:2–3). The accomplishment of human labour-power—

"work"—was, according to Borkenau, the primary object of contemporary analyses (1976:5, 7). In general, what was made possible was an extended quantification. This dividing up of manual labour

> realizes an immanent principle of all capitalist economy: calculability. For only pure quanta are completely commensurable, the comparability of quanta of labour is thereby connected to the reduction of all qualities of labour to generally human, purely quantitatively determined labour. (1976:8)

As a result, materials are considered only in terms of "primary qualities" as well: size, shape, weight, hardness (1976:8). A more complete scientific and economic control over the qualities of the substrate of labour, however, had to await the actual completion of the development of mechanistic science by the eighteenth century with a more complete subjection of the worker to detail labour (1976:10). Nonetheless, claims Borkenau, this provides enough for a preconception for the mathematical-mechanistic world-view. This view relates matter (the substrate of labour) and motion (the labour) in a unified picture of nature. Secondary qualities could then be viewed as reflexes of changes in pure matter.

While the mechanistic world-view represents an extension of "processes of manufacture to the entire cosmos" (1976:12), this extension is not dependent on the development of technical, productive forces. There is a description, of sorts, of labour and material in the manufacture period, but there is no direct transference to a mechanistic cosmology from the "manufactory shop-floor", as it were. The driving forces behind this extension and generalization, for Borkenau, were the social developments behind the eventual establishment of the new society in which manufacture gradually became the dominant method of production (1976:12–13). Not the relation of humans to nature, but their relations to one another were decisive in the establishment of the mechanistic world-picture.

> The mechanization of labour (productive forces) and of social life (production relations) are one and the same process of the onward movement (*Durchdringen*) of capitalism. In the manufacture period, however, as in all periods, it is the side of production relations which calls forth the theoretical generalization of that which in technology presents itself simply as material for thought. Against the technology of a time period, i.e., against the naturally conditioned process of exchange

> between the human and his/her environment, no world-picture can maintain itself. But what becomes of the thought-material of technology, depends on the relations of humans to one another. (1976:14)

Borkenau devotes the bulk of his work to analyzing the intellectual reflex of the class struggles that bring about manufacture and bourgeois society. His methodology for this is a

> historical presentation of the development of the concept of "natural law." The appropriate method for this is the history of the literal meaning of the term "lex naturalis," since from the thirteenth century on this term unites the idea of societal order with the concept of natural order. (1987:110–11)

Whatever the merits and insights of this procedure, it has been criticized with some success by Henryk Grossmann (1987); our own extension of Borkenau's lead will take the form of the latter's suggestion for further research in more specialized areas. Grossmann's criticism, apart from the question of "natural law" and its connection with class struggles, is a cogent one and must be addressed in some detail.

The English summary which accompanies the original 1935 issue of Grossmann's critique presents the alternative to Borkenau's conception as follows:

> The development of machinery, not the calculation with abstract hours of labor, is the immediate source of modern scientific mechanics. This goes back to the Renaissance and has relatively little to do with the original factory system that was finally superseded by the Industrial Revolution. (1987:130)

While in some measure the reference to calculating hours of abstract labour misrepresents Borkenau's position, the assertion that machinery provided the real basis for mechanism needs, nonetheless, to be addressed. Grossmann maintains (1987:132) that Borkenau does not describe the revolution in social relations which, he claims, was decisive for the constitution and proliferation of the new world-view. Grossmann recommends (1987:134) the illustration, with appropriate examples from special sciences, of the metamorphosis of basic categories. Borkenau, claims Grossmann, "got stuck in generalities." The present inquiry attempts a