What defines the character of intellectual labour in its full-fledged division from all manual labour is the use of non-empirical form-abstractions which may be represented by nothing other than non-empirical, 'pure' concepts. The explanation of intellectual labour and of this division thus depends on proving the origin of the underlying, non-empirical form-abstractions. This is the task we have undertaken. And we can see that this origin can be none other than the real abstraction of commodity exchange, for it is of a non-empirical form-character and does not spring from thought. This is the only way in which justice can be done to the nature of intellectual labour and of science and yet avoid idealism. It is Greek philosophy which constitutes the first historical manifestations of the separation of head and hand in this particular mode. For the non-empirical real abstraction is evident in commodity exchange only because through it a social synthesis becomes possible which is in strict spatio-temporal separation from all acts of man's material interchange with nature. And to my knowledge this kind of social synthesis does not reach fruition before the eighth or seventh centuries B.C. in Greece, where the first introduction of coinage around 680 B.C. was of fundamental importance. Thus we are here confronted with the historical origin of conceptual thought in its fully developed form constituting the 'pure intellect' in its separation from all man's physical capacities.

Extract from chapter 8, pp. 66-67

REIFICATION AT THE ROOT OF THE INTELLECT

It may be confusing to be told that the notion of nature as a physical object-world independent of man emerges from commodity production when it reaches its full growth of monetary economy. Nevertheless this is a true description of the way in which this conception of nature is rooted in history; it arises when social relations assume the impersonal and reified character of commodity exchange. We saw that in exchange the action is social whereas the minds are private, and that it is the physical action of the commodity transfer between the owners which is abstract. The action of exchange stands in antithetic polarity to the sense-reality of things in the private minds of the individuals in their social life. The non-empirical concepts drawn from the real abstraction describe that action reduced to bare-bone physical reality. It is a reality carrying universal social validity among all exchanging agents. These concepts have objective reality in application to natural events because they relate to form categories of physical events, of a kind which could be described as the absolute minimum of what can constitute a natural event, for they are events which happen while the material status of things undergoes no change. They constitute the paradigm of mechanistic thinking. Its concepts are, in their origin, the forms of the act of commodity exchange, and in their content the basic categories of nature as object-world in antithetic contrast to man's own social world. The content of these concepts bears absolutely no reference to money. Their only trait relating to money and to exchange is their abstractness. The abstractness itself is the work and outcome of exchange, but this fact is completely unrecognisable to any mind or 'intellect' using these concepts. Such an intellect is bound to be alienated by false consciousness when it tries to explain its own mode of thinking. The self-explanation assumes the materialistic or the idealistic variant according to whether its basic concepts are recognised as non-empirical or as derived from external reality. Non-empirical concepts cannot be explained in materialistic ways—that is, by way of direct reflection—and idealism is thus at an epistemological premium regardless of its blatant absurdities otherwise.

Chapter 9, section (e), pp. 72-73

KNOWLEDGE FROM SOURCES OTHER THAN MANUAL LABOUR

Owing to the concepts drawn from the exchange abstraction the intellect is equipped with instruments of cognition which, if employed in a suitable method, can yield a knowledge of nature from sources totally alien to manual labour. It is a knowledge ruled by a logic of appropriation, or, more precisely, by a logic of the reciprocal appropriation which rules in the market, as opposed to manual production. A logic of production could only be the logic of producers for the pursuit of their production, individually or in common. It would be a logic of unity of head and hand, whereas the logic of the market and of mechanistic thinking is a logic of intellectual labour divided from manual labour. Therefore, the concepts deriving from the exchange abstraction—that is the concepts of mechanistic thinking—we may term as 'original categories of intellectual labour'. It is a labour serviceable to the rule of private property and in particular to capital.

It is the science of intellectual labour springing from the second nature which is founded upon non-empirical abstraction and on concepts of an a priori nature. The form elements of the exchange abstraction are of such fundamental calibre—abstract time and space, abstract matter, quantity as a mathematical abstraction, abstract motion, etc.—that there cannot be a natural event its the world which could elude these basic features of nature. They make up between them a kind of abstract framework into which all observable phenomena are bound to fit. Anything descriptive of this framework such as, for example, the geometry of homogeneous space, would be applicable to such phenomena with a priori assured certainty, although, of course, is manner appropriate to the specific properties of the phenomenon concerned. While these properties in their infinite variety are conveyed through sense-perception and are as accessible to manual producers as to scientists, the conceptual issues are the exclusive prerogatives of the intellectual workers. It is this theoretical part which holds the epistemological problems. The main one among these attaches to the understanding of nature by its laws; to the possibility and conditions of such understanding.

Chapter 9, section (f), pp. 73-74
The discovery of natural laws was the set objective of the mathematical and experimental method of exact science as understood and practised in the classical Galilean-Newtonian era. The rise of modern science ran parallel with the rise of modern capitalism. In Part II of this study we shall analyse their formal and inherent connection; at present we are concerned to clear up the epistemological issue of science as raised by Kant, with whom we have one important point in common. Kant argued with great vigour and with a polemical edge against English empiricism that the discovery of natural laws presupposes the employment on non-empirical concepts such as, say, the concept of inertial motion as defined by Newton in his ‘first law of motion’. On the other hand, it is extremely difficult to see how such a concept, just because it is non-empirical and cannot be gleaned from nature or supplied by the practice of experience, could possibly give access to the inner workings of nature far beyond sense-perception. It was this contradiction which prompted Kant to turn the tables on all previous epistemological standpoints and to decide that, as the concepts of science could not be assumed to be modelled on nature, the only way to account for the facts of Newtonian science was to postulate that nature, or rather our human kind of experience, was modelled on the non-empirical concepts of our pure understanding. Now Kant was driven to this conclusion because he could not imagine that non-empirical concepts could possibly have natural or historical, or in any case spatio-temporal, roots. The same holds true for all philosophical materialists. To their minds anybody believing that non-empirical concepts play a vital part in science must be an idealistic thinker. Conversely, anybody resolved to adhere to his materialism is committed to hold mistaken ideas about ancient and bourgeois science. Our study is calculated to remedy this paradoxical situation. For we show that non-empirical concepts are not necessarily beyond the reach of materialistic explanation. We are therefore in a position to dismiss both these philosophies, idealist and materialist, and to follow historical materialism as our only methodological guideline.

Chapter 9, section (g), pp. 74-75

THE GUIDE-LINE OF HISTORICAL MATERIALISM

Marx contemplated human history as a part of natural history, a tangible part, as it were, which takes shape in the protracted process by which man succeeds in producing his own means of livelihood. This holds a promise that man will eventually assume control of his historical destiny, but until that stage is reached the development of mankind is the result of blind necessity and is as much a working of natural history as, say, the generation of a new biological species would be in non-human nature. But the difference is that history, by being channelled through human society, brings forth mental rather than physical alterations in man, developments like language, conscious reflection, faculties of knowledge together with those of error and human self-delusion and even possibly also of a social self-realisation of man. True, the nature from which the non-empirical categories of intellectual labour are drawn is not the primary nature of physical reality but the second, purely social nature which, in the epochs of commodity production, constitutes a vital part of that 'social being of men which determines their consciousness'.

However, the very categories which constitute second nature are products of man's natural history. 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 primary nature from sources other than manual labour. It seems paradoxical, but is nevertheless true, that one has first to recognise 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.

Chapter 9, section (h), p. 75

Mathematics, the Dividing-line of Intellectual and Manual Labour

In Chapter 13 we illustrated the proto-intellectual character of the mental work in the Bronze Age by describing the Egyptian geometry of the rope. We found it to be a highly efficient and multivariant art of measuring attaining useful and indeed astonishing grades of approximation. But it was in the character of a skill rather than of a science even though it depended on extensive geometrical interpretation and instruction as indispensable accessories to manual practice.

Admittedly, from my perspective, I would not place traditions handed down from the Bronze Age or even earlier on the same level as the mathematics created by the Greeks. They replaced the rope by ruler and compass and thus transformed the previous art of measurement so fundamentally that something completely new grew out of it—mathematics as we understand it. The geometry of the Greeks is of a purely intellectual character and detached from the practice of measurement. How could the change in the implementation achieve such a difference, or, rather, what transformation occurred to bring this change about?

The art of the rope was a manual skill which could only be carried out by those apprenticed to do it and practised in it and only at the particular spot where the need for measurement arose. Divorced from this it had no point. Neither did it leave behind any detachable demonstration of its geometric content. After each action of measurement, each ‘measure’, the rope was moved on from one position to another so that such a thing as a direct ‘geometrical demonstration' never came into question. The geometry inherent in the task at hand extinguished itself in the practical result, which was only ever applicable to the case in point. To be sure, the 'harpedonapts' in the course of their training had to be taught and shown the constantly recurring elements in their techniques and with Ahmes much of this is presented in the guise of geometric rules. But it must surely be nothing but a reflex of our own conceptions when mathematical historians (including Moritz Cantor, Sir Thomas Heath and D. F. Smith) conjecture that a theoretical manual must have existed serving as a foundation to Ahmes's book of practical exercises—a manual which has never been found.

The Greeks, however, invented a new kind of geometric demonstration. Instead of stretching ropes, they drew lines by ruler which remained on the sheet underneath, and together with more straight lines, formed a permanent figure from which could be recognised
The geometry of the measurement thus became something quite different from the measurement itself. The manual operation became subordinated to an act of pure thought which was directed solely towards grasping quantitative laws of number or of abstract space. Their conceptual content was independent not only from this or that particular purpose but from any practical task. In order, however, to detach it from such application a pure form abstraction had to emerge and be admitted into reflective thought. We reason that this could result only through the generalisation intrinsic in the monetary commensuration of commodity values promoted by coinage.

It goes without saying that this radical transformation from the Egyptian art of measuring to the geometry of the Greeks did not occur at one stroke, but only over hundreds of years and mediated by incisive developments to the productive forces and by corresponding changes in the relations of production. For proof of this one need go back no further than to the beginnings of Greek geometry. The invention which bears Thales's name is traditionally connected with the measurement of distance of ships from the coast; here the art of the rope would clearly have been useless. This one example illustrates the world-wide difference between the Bronze Age mainland economics of Egypt and Mesopotamia based on agrarian exploitation, and the Greek city-states based on sea-voyaging, piracy and trade. The Greek forms of production were peasant agriculture on a small scale, and independent handicrafts. The new monied wealth of the Greeks emanated solely from the circulation nexus, an achievement effected, as Lenin says, by merchants' and usurers' capital. It did not spring from the land or from the workshops of manual producers, at least not before these were replaced by slaves, who themselves became the source of commodities for exchange.

An essential point regarding the 'pure mathematics' of the Greeks is that it grew to be the unbridgeable dividing-line between mental and manual labour. This intellectual significance of mathematics is a central theme with Plato. Euclid, in his 'Fundamentals of Geometry', created an imperishable monument to it at the threshold of Hellenistic culture. This work seems to have arisen for the sole purpose of proving that geometry as it deductive thought structure was committed to nothing but itself. In the synthetic quality of thought no account was taken of the material interchange of man with nature either from the point of view of the sources and means involved, nor from that of its purpose or use. Into this glasshouse of Greek thought went 'not a single atom of natural matter'—quite parallel with commodities and their fetish identity as 'value'. It was the pure formalism of 'second' or 'para-'nature and suggests that in antiquity the form of money as capital, in other words the functionalism of second nature, finally remained sterile. Although it had indeed freed labour from slavery it had failed to lower the reproduction cost of human labour power in any noteworthy way, if at all. We can conclude this to be true in retrospect from the fact that development after Euclid by Archimedes, Erastosthenes, Apollonius, the legendary Heron and many others, in whose mathematical elements of abstract dynamics were already noticeable, consequently achieved technical application limited only to military or other wasteful ends.

Chapter 15, pp. 101-103

The Forms of Transition from Artisanry to Science

Medieval handicraft began with the personal unity of head and hand; Galilean science established their clear-cut division. In this chapter we are concerned with the transition from artisanry to science from this viewpoint. The causes of the transformation can be found in the change from one-man production to production on an ever-increasing social scale. This occurred, as we have seen, mainly as a result of the commercial revolution.

The formation of towns as urban communities started in the era of late feudalism. With their development sprang the need for communal walls, communal defences, communal town halls, cathedrals, roads and bridges, water-supplies and drainage systems, harbour installations and river control, monuments and so on. These were all due to the activities of capital, commercial and monetary, 'antediluvian forms of capital', as Marx calls them. The social character of all this development is the direct outcome and manifestation of the originally social power of capital. Under this power the great mass of the artisans were ruthlessly exploited. They still retained the status of producers owning their own means of production, but the bulk of them did so as impoverished cottage labourers, hopelessly indebted to the capitalist for whom they produced the merchandise. They were downgraded and depressed to the standard of proletarian labour long before they actually assumed the status of mere wage-labourers. Production taking place in artisan workshops, on the other hand, increased in volume and changed in labour methods. The employment of more and more semi-skilled workers resulted in class divisions within the workshops.

From our viewpoint, however, these economic and sociological changes are not the main focus of interest. They, are not the ones that can explain the logical and historical steps leading to the formation of science. Parallel to the economic developments making for the eventual dissolution of the artisan mode of production go technological changes caused by the increasingly social scale of the order of life as a whole exemplified by the town developments.

Construction and production tasks of such dimensions and novelty stretched the craftsmen to the limits of their resources and inventiveness. By the necessity to tackle the problems there rose from the ranks of ordinary producers the great Renaissance craftsmen, the 'experimenting masters', artists, architects, and also engineers of the fifteenth and sixteenth centuries. The main qualification which the craftsmen lacked in their capacity as artisans for solving the problems facing them can be named in one word—mathematics. We have defined mathematics as the logic of socialised thought. Capital and mathematics correlate: the one wields its influence in the fields of economy, the other rules the intellectual powers of social production.

We must be clear about the limits that are set to the capacity of work tied to the personal unity of head and hand. The artisan or individual manual worker masters his production, not through abstract knowledge, but by practical 'know-how' and by the expertise of his hands. In terms of 'knowledge', it is the knowledge of how one does, not of how one explains things. This practical knowledge can be
conveyed by demonstration, repetition or words, depending on practical understanding of the task involved. Cookery books are a clear example. This is, moreover, not only true of human functions. Let us suppose we deal with working a pump, a threshing-ﬂail or a water mill, irrespective of whether they replace human labour or whether man cannot perform their task. In speaking to manual workers one could not express oneself in any other way than by treating these things as if they took the part of human agents. The language of common usage (devoid of special technical terms) cannot articulate a division of intellectual and manual labour. The only symbol common language which rends itself free from this tie-up with human activity is that of mathematics. Mathematics cuts a deep cleft between a context of thought and human action, establishing an unambiguous division of head and hand in the production processes.

It is no exaggeration to say that one can measure the extent of division of head and hand by the inroad of mathematics in any particular task. More than any other single phenomenon it was the development of firearms which imposed the use of mathematics on artisanship. Needless to say, the technology of firearms did not cause the dialectic of the precapitalist development, but from the second half of the ﬁfteenth century it intensiﬁed and accelerated technological developments enormously. The use of firearms was confined to guns for artillery, and in this capacity created problems completely new and alien to artisan experience and practice—problems such as: the relationship between the explosive force and the weight of cannon and range of ﬁre; between the length, thickness and material of the barrel; between the angle and the resulting path of ﬁre. Metal-casting assumed new proportions, as did the mining of ore, the demands of transport, and so on. Special importance accrued to military architecture for the defence of cities and harbours. From the fall of Constantinople to the Turks in 1453 well into the sixteenth and even seventeenth century the Turkish menace hung over Europe like a nightmare. After the fall of Ostrando in the Adriatic in 1490 Venice felt under the threat of immediate assault and in 1532 the Turks laid siege to Vienna.

To gauge the strain and stresses which the urgency of this turn of events laid upon European artisanship would demand a study beyond our scope. We can, however, gain an illuminating insight into the contradictions of the epoch by drawing upon the writings of Albrecht Dürer (1471 - 1528) as a master in both the arts and mathematics. My remarks are based on Instructions of Measurement with Compass and Ruler (1525) and on the Instruction as to the Fortiﬁcation of Town, Castle and Hamlet (1527). Here the unique attempt is made to refashion mathematics to make it a ﬁtting discipline for the use of artisanship. This means, of course, to attempt the impossible. Nevertheless his venture was so signiﬁcant that it occupied mathematicians and military architects of the whole of the sixteenth century and to some extent up to the eighteenth century.

Dürer had studied mathematics at the highest academic level of that time with his learned friends in Nuremberg, Willibald Pirckheimer and Johann Werner. Instead, however, of using this knowledge in its scholarly form he endeavoured to put it to the advantage of the craftsmen. The work is dedicated to ‘the young workers and all those with no one to instruct them truthfully’. It aims to change geometry by modifying its implements; he replaces the ruler by the set-square and alters the use of the compass by restricting it to a ﬁxed aperture. According to generally accepted surmise Dürer, for this, drew on the tradition of workshop practice and in particular of that of the mason lodges. What is novel in his method is that it tries to combine workmen’s practice with Euclidean geometry, and to reconcile these two seemingly incompatible elements by aiming at nothing more than approximate results sufﬁcient for practical needs. He writes: ‘He who desires greater accuracy, let him do it demonstrative, not mechanice as I do it.’

As Moritz Cantor points out: ‘Albrecht Dürer is the ﬁrst to apply the principle of approximation with full awareness.’ Only in his construction of the pentagon does Dürer neglect this distinction, presumably because he takes it to be accurate, albeit erroneously. ‘The fact that he otherwise makes such a clear distinction between what is correct and what is of practical use places him on a plane of science reached by hardly any other geometrical of the 16th century.

On the subject of Dürer’s construction of the pentagon Leonardo Olschki writes: ‘The construction of the regular pentagon by this method [the ﬁxed-compass aperture—S.-R.] exercised the wits of such mathematicians as Tartaglia, Cardano, G. del Monte, Benedetti and others, until ﬁnally P. A. Cataldi devoted a special dissertation on it which appeared in Bologna in 1570.’ He was a member of the Florentine Accademia del Disegno, where twenty years later Galileo also taught. Galileo too dealt with Dürer’s construction in his lectures on military architecture of 1592-3, and even Kepler, in his Harmonices Mundi (1619), still discussed Dürer’s construction of the septagon.

What Dürer had in mind is plain to see. The builders, metal workers, etc., should, on the one hand, be enabled to master the tasks of military and civil technology and architecture which far exceeded their traditional training. On the other hand, the required mathematics should serve them as a means, so to speak, of preserving the unity of head and hand. They should beneﬁt by the indispensable advantages of mathematics without becoming mathematical brainworkers themselves; they should practice socialised thinking and yet remain individual producers. And so he offered them an artisan’s schooling in draughtsmanship, permeated through and through with mathematics (not to be confused in any way with applied mathematics). Nothing can illustrate the inner paradox of the pre-capitalist mode of production more clearly than this attempt of Dürer’s: nothing can so illuminate the interrelationship of the intellectual form development with the economics of the conditions of production than its fate. It met with failure on both counts.

To do justice to the inner nature of this achievement of Dürer is impossible here. Two or three quotations must sufﬁce to illustrate it. His stereometric constructions in the Fourth Book of the Instructions of Measurement end: ‘Here I have drawn up everything quite openly after which I closed it, laid it on the ground and opened it up once more.’ In numerous constructions he points out ways in which they could prove useful to his work-mates; here, for instance, with the doubling of the cube: ‘In this way they could duplicate, triplicate and inﬁnitely increase and augment the cube and all other things. Now as such an art is of great use and serves the end of all workmen but is held by all the learned in the greatest secrecy and concealment, I propose to put it to the light and teach it abroad. For with this art, ﬂails or a water triplicate and barrels, chests, gauges, wheels, rooms, pictures and what you will, enlarged. Thus let every workman heed my words, for they have never, to my knowledge, been given in the German language before this day.’ From the squaring of circles: ‘Mechanice, that is approximately, so that at work it will fall short of nothing or of very little, and could be put by comparison as follows...’ Regarding approximation: ‘Now I shall change a previous triangle into a septangle through a common trick which we need to speed up...’
It is true that Galileo did not formulate this definition to advantage. For a fuller description of the salient characteristics of science. Capitalism. In order to do this study is to show that the rise of modern science is not only outwardly and then tested experimentally. This cannon ball proved experimentally to conform with this rule advanced by way of hypothesis, notably the case with the ballistics of gunnery which in turn governed the entire range of military engineering and architecture when Europe was gripped by the fear of the Turkish menace (from the fall of Constantinople 1453 and of Otranto 1490).

The calculation of the trajectory of cannon balls was among the foremost problems on which Galileo brought to bear his concept of inertial movement and which he was the first to solve successfully. He proved it to be an exercise of pure mathematical analysis consisting of the combination of two geometrical principles, that of a straight line with a horizontal or an upward tilt and that of a vertical fall involving an even acceleration of known arithmetical measure. The combination yielded a parabola and the actual trajectory of cannon balls proved experimentally to conform with this rule advanced by way of hypothesis, while making allowance for air resistance. We know that Newton later repeated on an astronomical scale in his calculation of celestial orbits the feat which Galileo performed in terrestrial mechanics.

The Galilean assumption of inertial motion opened the applicability of mathematics to the calculation of natural phenomena of motion. This calculation carries scientific reliability, providing that the phenomena can be isolated from uncontrolled environmental influences and then tested experimentally. This briefly epitomises the guiding features of the mathematical and experimental method of science which, in turn, signifies the epistemologically most telling part of the Scientific Revolution associated with the name of Galileo. Our aim in this study is to show that the rise of modern science is not only outwardly coincident but inherently connected with the rise of modern capitalism. In order to do that we must give a historical-materialist account of the origin and inner possibility of the method of modern science.

For a fuller description of the salient characteristics of this method I draw on Alexandre Koyré, whom I regard as one of the most distinguished exponents of the history of science as an internal history of ideas. His is an idealistic witness, but one which I intend to turn to advantage as an added test of the materialistic interpretations here proposed. I quote from his essay on 'Galileo and the Scientific Revolution of the Seventeenth Century', which is a good summary of his extensive Galilean investigations.

Modern physics, which is born with and in the works of Galileo, looks upon the law of inertial motion as its basic and fundamental law. . . . The principle of inertial motion is very simple. It states that a body, left to itself, remains in a state of motion so long as it is not interfered with by some external force. In other words, a body at rest will remain eternally at rest unless it is 'put in motion', and a body in motion will continue to move, and to persist, in its rectilinear motion and given speed, so long as nothing prevents it from doing so.
The immediate successors to Galileo, Descartes and Torricelli, are quite clear on the non-empirical character of Galileo's novel dynamic principle. Newton gave it the final acknowledgement under the name of 'the first law of motion'. There is thus no possible doubt that Galileo's own description in the Discorsi must be discounted and that the correct interpretation is the non-empirical one of 'the uniform motion in a right line'—to use Newton's phrasing. Koyré is well justified in emphasising this true aspect of the principle which does not always receive its due attention.

'The principle of inertial motion', he continues where we quoted him before, 'appears to us perfectly clear, plausible, and even, practically, self-evident. . . . The Galilean concept of motion (as well as that of space) seems to us so "natural" that we even believe to have derived it from experience and observation, though, obviously, nobody has ever encountered an inertial motion for the simple reason that such a motion is utterly and absolutely impossible. We are equally well accustomed to the mathematical approach to nature, so well that we are not aware of the boldness of Galileo's statement that "the book of nature is written in geometrical characters", any more than we are conscious of the paradoxical daring of his decision to treat mechanics as mathematics, that is to substitute for the real, experienced world a world of geometry made real, and to explain the real by the impossible.

In modern science motion is considered as purely geometrical translation from one point to another. Motion, therefore, in no way affects the body which is endowed with it; to be in motion or to be at rest does not make any difference to, or produce a change in, the body in motion or at rest. The body as such is utterly indifferent to both. Consequently, we are unable to ascribe motion to a determined body considered in itself. A body is only in motion in its relation to some other body, which we assume to be at rest. We can therefore ascribe it to the one or to the other of the two bodies, ad lib. All motion is relative. Just as it does not affect the body which is endowed with it, the motion of a body in no way interferes with other movements that it may execute at the same time. Thus a body may be endowed with any number of motions which combine to produce a result according to purely geometrical rules, and vice versa, every given motion can be decomposed, according to the same rules, into a number of component ones. . . .

'Thus, to appear evident, the principle of inertial motion presupposes (a) the possibility of isolating a given body from all its physical environment, (b) the conception of space which identifies it with the homogeneous infinite space of Euclidean geometry, and (c) a conception of movement—and of rest—which considers them as states and places them on the same ontological level of being.'

With his usual brevity Bertrand Russell summarises:

Galileo introduced the two principles that did most to make mathematical physics possible: The law of inertial motion, and the parallelogram law.

The vital importance of the principle of inertial motion is that it has the element of motion in common with innumerable phenomena of nature and at the same time it is co-extensive with mathematics and can be treated like Euclidean geometry 'made real', as Koyré puts it. It thus opens the door through which mathematics can establish itself as an instrument of the analysis of given phenomena of movement and yield a mathematical hypothesis which can then be tested experimentally. The concept of inertial motion is the methodological key to exact science. The crucial question is—from what origin does it spring?

We face the contradiction that concepts which are incontestably non-empirical—that is, not gleaned or reflected from nature—can nevertheless give such invaluable service in the investigation of nature. Whether or not the knowledge achieved is proved valid by experiment or by industrial or social practice is, of course, the vital question. But our concern is the possibility of such knowledge which, in order to be available for practical confirmation or refutation, depends on whether the concepts bear the necessary reference to nature at all. And how such reference is possible of concepts which are not taken from nature is the pivot of our enquiry. It can, without exaggeration, be called the particular epistemological riddle of exact science. It was asked by Kant as an enquiry into 'the possibility of pure mathematics and of pure science'. He saw no possible answer other than the one given in his 'transcendental idealism', that, since our knowledge depends on concepts a priori not depicting nature as it really is, we can only understand nature as it corresponds to those concepts of ours. In Part I of the present book we have, however, laid the foundation for a different answer, a materialistic one, while changing Kant's ahistorical question to the historical one, to read: How is knowledge of nature possible from sources other than manual labour? or: How is mathematical physics possible given the fact that it cannot be derived from manual labour? How does man acquire an intellectual capacity of knowledge of nature that far exceeds the standards accessible to handicrafts?

Our explanation of the principle of inertial motion is that it derives from the pattern of motion contained in the real abstraction of commodity exchange. This motion has the reality in time and space of the commodity movements in the market, and thus of the circulation of money and of capital. The pattern is absolutely abstract, in the sense of bearing no shred of perceptible qualities, and was defined as: abstract linear movement through abstract, empty, continuous and homogeneous space and time of abstract substances which thereby suffer no material change, the movement being amenable to no other than mathematical treatment. Although continually
And in his Preface of the first edition Marx speaks of

My standpoint, from which the evolution of the economic formation of society is viewed as a process of natural history . . . (p. 21)

Thus my derivation of the concepts a priori of science is a natural one, not relating, it is true, to the external nature but to the historical nature of man himself.

We must now explain the different concepts of inertia—static in the ages of pure commercial and slave-holding capital in antiquity, and in the Middle Ages and the Renaissance, but dynamic from the start of capitalist production. The first remains as long as the exchange processes are confined to the sphere of circulation as is the case of merchant and monetary capital until the sixteenth century. But as society enters upon a state where the direct producers are without their own means of production then these means of production, both material and men, are brought together by way of the market. Then production does not take place merely as production but as exchange, and exchange no longer signifies only exchange but production. This mingled unity of exchange and production, production and exchange, constitutes a constant and continuous process functioning as an economically self-compelling system. Production here is of larger volume and

Capitalist production only really begins when each individual capitalist employs simultaneously a comparatively large number of workers, and when, as a result, the labour-process is carried on on an extensive scale and yields relatively, large quantities of products. . . . [This] constitutes the starting point of capitalist production. This is true both historically, and conceptually.

In other words capital is a social power which takes over production where it has outgrown the economic and technological capacities of the direct producer controlling it himself. While in the economic field the social power is capital, in the field of technology it is science, or, more accurately, the methodical operation of the human mind in its socialised form, guided by its specific logic, which is mathematics. This socialised mind of man, we have seen, is money, without its material attachments, therefore immaterial and no longer recognisable as money and, indeed no longer being money but the ‘pure intellect’. In its form as money it is capital ruling the labour process by the identity of labour with value and postulating the process to be cast in a framework in which it operates in an automatic manner enforcing the embodiment of the labour employed into values containing a surplus. In its form as the scientific intellect the socialised mind applies itself to physical phenomena on which the automatic working of the labour process of the various capitals is found to be depending. I turn once more to Bertrand Russell's Human Knowledge to illustrate this context. The first sentence of the book reads:

Scientific knowledge aims at being wholly impersonal, and tries to state what has been discovered by the collective intellect of mankind. (p. 17)

On page 30 we find the statement:

This principle [of inertial motion] led to the possibility of regarding the physical world as a causally self-contained system.

The establishment of natural laws we can understand as resulting from a combination of mathematical hypotheses and experiments. How this is helped by, and indeed founded on, the principle of inertial motion, or, let us say, how this was done in classical physics can be further clarified by considering the following statements, one by Engels, the other by Bertrand Russell: In Anti-Dühring we read:

Motion is the mode of existence of matter. Never anywhere has there been matter without motion, nor can there be. Motion in cosmic space, mechanical motion of smaller masses on the various celestial bodies, the motion of molecules as heat or electrical magnetic current, chemical combination or disintegration, organic life—at each given moment each individual atom of matter in the world is in one or other of these forms of motion, or in several forms of them at once.

And in his History of Western Philosophy Russell states:

The theory that the physical world consists only of matter in motion was the basis of the accepted theories of sound, heat, light, and electricity.
The association of matter with motion stems from Galileo's definition of inertia. This definition, we have seen, was the finishing touch enabling Galileo to work out the mathematical and experimental method and to become the founder of modern science. In the light of Galileo's definition of inertia the pattern of the exchange abstraction assumes the meaning of the absolute minimum of what constitutes a physical event. Any event that can be constructed as a composite of this minimum is therefore (ipso facto) conceivable in terms of pure theoretical categories and amenable to full mathematical treatment. This is, in fact, how modern science proceeds. Theoretical hypotheses in conceptual form and mathematical formulation are worked out and tested by confrontation with nature or with that carefully isolated part of nature of which the hypothesis contains the definition. This confrontation represents the experiment. The experiment is carried through with the help of instruments adapted to the hypothesis and are, in fact, part of it. The phenomenon tested is safeguarded from any touch by human hand and made to register specific measurements which are then read as indicated by the instruments, and which must be in answer to the questions advanced by the hypothesis. The act of reading these values is the only direct contact the experimenter is allowed with the piece of nature under investigation. These precautions are indispensable for ascertaining the identity of the tested phenomenon with the mathematical hypothesis; in other words indispensable for clinching the experimental isolation. Owing to this isolation a phenomenon can be subject to investigation only torn out of the context within which it occurs. It is clear, therefore, that modern science is not aimed at helping society in her relations with nature. It studies nature only from the viewpoint of capitalist production. If the experiments yield a reliable verification of the hypothesis the latter becomes an established 'law of nature' in the shape of a law of recurrent events. And this is the result the capitalist may utilise for technological application in his factory. Not infrequently the technological installation closely resembles a large-scale replica of the successful experiment. It can be said that objects over which capital can exercise control must be cast in the form of a commodity. It is the exact truth of exact science that it is knowledge of nature in commodity form.

Chapter 19, pp. 123-132

Science and technology have developed to new forms. But while classical physics is securely based on its mathematical and experimental method, the relativity theory and quantum physics have thrown science into methodological uncertainty. Classical physics in its unchallenged reign shared the lifespan of modern capitalism up to the end of its classical free-market period. Although now relegated to second place, it still has an important role to play and remains an adequate scientific method for a great mass of the technological tasks in the present world, not excluding the socialist parts. Were we then entitled to speak of classical science as 'bourgeois science' as we did in Chapter 20?

Let us be quite clear: methodologically, classical physics has nothing to do with the exploitation of labour by capital. Its findings are valid irrespective of any particular production relations. Inasmuch as it is based on the mathematical and experimental method science is one and one only. Exact science carries objectivity because the elements of the exchange abstraction, which in themselves are entirely of the second nature, have substantial identity with the corresponding elements of real nature owing to the fact that the separation of exchange from use and hence the creation of the exchange abstraction itself happens as an event in time and space in every occurrence of exchange.

On the other hand, looking at nature under the categories of the commodity form, science affords precisely the technology on which hinges the controlling power of capital over production. It cuts up nature piecemeal by isolating its objects of study from the context in which they occur, ignoring nature in its importance as the habitat of society. The environmental conditions are treated as a mass of interfering circumstances which must at all cost be kept out of the experiments. In this way the phenomena are severed from the human world and cut down to recurrent events; these are defined by mathematical equations signifying the description of immutable 'laws of nature' providing the automatism demanded by capital. True, this deterministic and orthodox concept of natural law has in more recent times been increasingly supplemented by statistical laws and therewith strict necessity by probability. However, the pattern of exact science is still fundamentally that of classical physics.

It is a pattern of science closely connected with the division of intellectual and manual labour. In fact, it forms the hard core of this division since the intellect is the very creation of the exchange abstraction circulating as money and again as capital. The practice of science in the service of capital pays allegiance to an idea of the intellect which is a fetish concept of the human mind seen as the spontaneous source of the non-empirical concepts basic to science. In the framework of this fetishism the science of the mathematical and experimental method is indeed bourgeois science, the scientists pursuing their vital social tasks while being steeped in false consciousness about their function and the nature of science itself. Our attempt to retrace the intellectual powers of conceptual reasoning to the real historical roots in the social systems of commodity production serves the critical liquidation of this fetishism and its epistemological doctrine.

Extract from Chapter 35, pp. 179-180

In Stalin's famous or notorious 'Plan for the Remaking of Nature' science, and the special science of biology and plant-breeding, was discarded because the isolating method of genetical selection was judged to be bourgeois in essence and incompatible with the alleged Marxian truth of 'dialectical materialism'. Here a science is discarded, not in the light of new research of superior scientific validity, but simply on the strength of a philosophical belief in 'dialectical materialism' regarded as an a priori truth. It is well known that the substitute for the orthodox biological science was provided by T. D. Lysenko and that with Stalin's connivance all the geneticists opposing Lysenko were ousted from the Lenin Academy of Agricultural Science of the U.S.S.R. in the Session of July - August 1948. The course of action advocated by Lysenko and adopted by Stalin and the Party proved bogus and condemned the much-boasted plan to failure, entailing considerable damage to Russian agriculture.

Here a project had been conceived for tackling nature as a whole, like the project of the T.V.A. though on a vastly more grandiose scale.
and by a government professing to be socialist. But while the T.V.A. made the greatest possible use of science and advanced technology, Stalin relied on the doctrine of reflection and the associated materialist metaphysics. There was emphasis on basic democracy in the execution of the plan but the masses did not benefit and the attempt at breaching the division of intellectual and manual labour remained unavailing.

What emerges from these examples is, first, that the science indispensable for socialism is methodologically the same as the science in capitalism; second, that socialism has the means to counteract the properties which, in capitalism, constitute the bourgeois character of this science. These properties are: that the basic categories of science are of the second nature and totally alienated from the qualitative realities of the first nature; that science is compelled to single out its objects as isolates; and that it must be carried out as an intellectual exploit.

All these properties are capable of remedy by the feature, the essential one of socialism, that the people as direct producers must be the controlling masters of both the material and intellectual means of production, and that they act in concert to establish their prosperity within nature in its global unity. For this feature signifies that the material practice of the people in their social exploits commands the need for scientific findings to be integrated into the relationship of society to nature. In the service of capital the findings of science are each of them items in commodity form presented to capital for its exploitation. This position does not alter when a number of such findings are combined to be exploited in their association; whereas in the practice of a socialist project, as evidenced also by the work of the T.V.A., the findings of science never remain single, but are always combined under the logic of production regulating any collective interaction with nature.

The difference then between the status of science in capitalism and in socialism is not in that the logic of science will change from a logic of appropriation to one of production. It is rather that the relationship between them differs. In capitalism the logic of appropriation reigning in the economics of profit-making and in science dominates the logic of production in the manual activities of the wage-labourers, whereas in socialism the relationship is the opposite: that the logic of production animating any socialist project dominates the logic of appropriation of a science belonging to the producers. It cannot, of course, be ruled out that in the long run the logic and method of science will alter as a result of socialist developments. But what is certain to change is the technology taken over from capitalism. And this change will not only be one of the machinery itself but also a change in the manner of producing it. Its construction will increasingly become the work of the direct producers rather than that of professional experts. We can see many examples of this change in China, particularly since the Cultural Revolution. Given a new, qualitatively different technology a new theoretical conception of its mode of working may emerge deepening its understanding and giving it the universality needed for its general social utilisation.

Extract from Chapter 36, pp. 183-184


Note: Footnotes have been stripped from the original text. These sections were selected with Sohn-Rethel's interest in the nature of science in mind, not necessarily out of agreement with them. Sohn-Rethel shares with George Thomson the thesis that the real abstraction of commodity exchange enabled the creation of ancient Greek philosophy. Sohn-Rethel also analyzes the nature of capitalist production, exploitation, and Taylorism. [—RD]
Critique of Philosophical Epistemology. The Fetishism of Intellectual Labour Can there be Abstraction other than by Thought? The Commodity Abstraction The Phenomenon of the Exchange Abstraction Economics and Knowledge The Analysis of the Exchange

(k) Concluding Remarks to the Analysis 7 The Evolution of Coined Money 8 Conversion of the Real Abstraction into the Conceptual Abstraction 9 The Independent Intellect (a) Self-alienation and Self-direction (b) The Relational Shift (c) Conversion post jestum of Exchange 2 3 4 5 6, 13 17 19 22 29 35 39 43 46 48 49 52 53 54 56 58 60 67 67 68 70. Intellectual and manual labour. VI. Intellectual and manual labour. A critique of epistemology. Alfred Sohn-Rethel. B o g a z i c i U n i v e r s i t y L i b r a r y. VI Intellectual and manual labour. (d) Division of Society and Nature (e) Reification at the Root of the Intellect (f) Knowledge from Sources other than Manual Labour (g) Laws of Nature (h) The Guideline of Historical Materialism (i) Money as a Mirror of Reflection (j) The Social Form of Thinking (k) The Social Synthesis as the Foundation.