CHAPTER TWO

HOW MAN HAS LEARNT TO THINK SYSTEMATICALLY AND GAIN A MASTERY OVER FORCE AND MATTER

§ 1. *Directed Thinking.*
§ 2. *The Criticism of the Instrument of Thought from the Beginnings of Directed Thinking Onward; Nominalism and Realism; Experiment; The Renascence of Science.*
§ 3. *The Practical Nature of Renascent Science.*
§ 4. *Ultimate Truths Are Outside the Diagrams of Experimental Science.*
§ 5. *The Organization of Modern Research.*
§ 6. *The Conquest of Substances.*
§ 7. *Some Typical Modern Materials.*
§ 8. *The Story of Iron and Steel.*
§ 9. *The Conquest of Power. Sources of Power.*
§ 10. *Transmission of Power.*
§ 11. *Points of Application.*

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§ 1. *Directed Thinking*

BUT before we go on to the actual panorama of present things, we must, if the whole spectacle is to be made understandable, go a little more fully into one particular aspect of history, the history of human thought. Human thinking has passed through several stages in its evolution, and most of us repeat those stages in our individual lives. The way we do business with each other and set about the affair of life is conditioned altogether by the way in which we think. Most of us do not think enough about thinking.

We have explained how round about five-and-twenty centuries ago the appearance and wide use of money and monetary credit in the world produced a new epoch in human affairs. It was an epoch of enlargement and extension. Mainly through the action of this new flux, money, the huge, unstable Roman system and the associated Byzantine system were able to develop—and collapse. But much more than the expansion of a novel political and economic system occurred at that time. These political expansions and instabilities were reflected in men's thoughts about life and divinity. These were intellectual consequences of far greater and more permanent importance than the material changes. In the *Outline of History* the appearance of syncretic and universal religions, for example, is traced to the expansion of these empires; they destroyed the prestige of the local and national gods. The idea of widespread brotherhoods and world unity dawned.

And simultaneously came a slower and ultimately still more important change in human affairs, though for a time it did not have anything like the same conspicuousness amidst the general appearance of life. This was an intellectual movement, a change in the way in which man did his thinking and came to his conclusions. He began to be more careful of the mental processes through which he took hold upon things. He began to think about thinking, to take care about his thinking, and to learn to think.

That was destined to have gigantic effects later on. We are indeed living amidst its gigantic effects, but at the time, for twenty centuries indeed, this intellectual revolution and reconstruction was an affair of the study and classroom, and the mass of mankind knew nothing about it. Even those who were concerned in it may not have realized its full importance.

Let us be perfectly clear about this "learning to think." Children, like primitive man, have still to learn to think; they do a large part of their thinking by imagination. That is, so to speak, the natural way with the untrained mind. Their thinking is a flow of images with which impulses to act are connected. Images and scenes are suggested and give rise by various forms of association to others. The whole flow is pervaded by a sense of wilful activities. It is spontaneous and uncontrolled. Many people in adult life are able to recall a time in their lives when they did all their thinking in that fashion. Many adults never think in any better way.

In the mental flow of child or savage, moreover, things are not distinguished very clearly from persons; they are thought of as quasi-persons. That is another great difference between the untrained and the trained mind. All things are liked or disliked; they can be friendly or inimical. The world of primitive thought is a drama in which the thinker conceives a rôle for himself. The flow of fantasy proceeds and gives an agreeable or disagreeable quality to this or that imagined line of action, which is followed or rejected accordingly.

The thought of the young child, the thought of the primitive mind, is a type of mental activity differing from dreaming only in its closer touch with reality, in its more frequent checking through the waking senses. Otherwise it is a quite undisciplined and undirected flow. There is hardly any use in it of generalizations and abstract ideas. There is no critical element asking, "But is this sound? Is this true?" Everything presented in the flow that is not itself physically real is apprehended in a symbolical and often a personified form. The idea of the winds, of the seasons, of the tribal organization, of the obligation to do right, for instance, appears under the guise of personalities or personal relationships. Everything is supposed to *do* something. Everything that happens is supposed to be *done.* The wind blows. It seems natural to ask: Who blew it? The river flows. Who poured it out? The sun rises. Someone has driven it up the sky. So we get Boreas or Auster, Father Tiber, Apollo, the charioteer of the sun. Every tree must have a spirit, just as man has a spirit, and how can there be thunder without a Thunderer? Father and Mother, at this mental stage, furnish patterns for the imagining of gods. Jove-pater stalks across the universe terrible and incalculable—with an immense beard and a voice of thunder. We cower to the bosom of the Earth Mother, mother of all the gods. She is the nourishing Mother, the Cow-goddess Athor, Mother Nature. The unsophisticated savage remains a child throughout life. To the end of life the primitive mind thinks in this way. Throughout the opening cycles of human history there was no other method of thought. All mankind thought then as our children think now.

This corresponds to what Comte called the mythological phase of human development. It has recorded itself in a vast mass of imagery in language and of images and pictures in the world. The gods and monsters who sprawl across an Indian or Maya sculpture frieze are thoughts embodied. Osiris, Horus, Anubis, and Isis express ideas of command and obligation and of good and evil for which man could devise no simpler, less encumbered expression. The eyes that a savage paints on the prow of his canoe betray this same entanglement of his mind with personality.

Only very gradually, as minds ripened and as mankind ripened, does an exacter discrimination and disentanglement of essentials appear, and logical thinking begin. The mythological passes insensibly into the metaphorical. With an increasing vocabulary, abstraction becomes possible to the growing mind. We *disentangle.* Goodness and benevolent power in the world can be thought of without evoking the figure of an armed and crowned chieftain bearing all the symbols of majesty; a boat can be considered as a floating contrivance which does not need an eye. The mind begins to arrest and examine its flow of association; to classify things in this way and then in that; and to pick out what is necessary from what is accidental and incidental.

On that follows "logical" thinking. Man, as he "grows up," begins to reason things out instead of dreaming them out. He begins to control his predispositions and observe a logical coherence. He restrains and criticizes his impulsive judgments and responses. He struggles to control and direct their sequences. He begins to squeeze the inessential associations out of his metaphors and symbols. The Athenian philosophical literature, culminating in Plato and Aristotle, records man's definitive adoption of what psychologists call *directed thought* as distinguished from *undisciplined thought*. The paraphernalia of personification which was once necessary had become an inconvenience and a burden. Gods, demigods, demons and fates faded into figures of speech and receded from the arena of judgment, while concepts of a more abstract order, forces and matter, atoms and reactions, were adopted to replace them. Much that was inessential still lurked in the new terms and abstractions, but the effort to get rid of that inessential element continued.

So, in that phase of human development which opened about six centuries B.C., man definitely ceased to take the results of his mental processes for granted. A scrutiny of those processes began. He had found them clumsy and inexact and he had set himself to sharpen them as once his ancestors had set themselves to sharpen flints. He had set himself to chip off the unnecessary.

And also he had ceased to take the world of appearance about him for granted. He had begun to scrutinize and question his world.

In the *Outline of History* Plato is taken as the typical exponent of a novel and inspiring idea, that man is able, if he will, to change his way of living. Aristotle stands beside him in that account, as the first organizer of the collection and classification of knowledge. They questioned custom, and they questioned appearance. Each of these men was in reality greater and less than this, but it is convenient here to use their names and their outstanding qualities as landmarks. We pick them out to simplify our story. In these two men we find the human mind turning upon its primitive methods and seeking a clearer and more serviceable form of interpretation, that will give, they realize, a hitherto unimagined mastery over fact and one's practical reaction to fact. Man, as they embody him, man in the Athenian phase, wrestles with his impressions, classifies them, seeks to clear and order them by exactly defined words, because he is realizing that ignorance is danger, and knowledge, power. He is changing from responsive imaginations to logical thinking directed towards the attainment of practical working truth.

The psychological chapters of the *Science of Life* deal rather more fully than is possible here with this substitution of orderly and directed thinking for the symbolism and imaginative play that was once the only human method, and which is still perhaps the most ordinary way of thinking. And in the *Science of Life* how this arose out of the still more primitive blind try and thrust of the animal life is explained very simply and clearly. Animal behaviour, it is shown, has three main stages of complexity. ("Main stages," we write; not distinct and separate stages.) First, instinctive and conditioned responses; then, imaginative thought before action; then, logical thought before action. It is unnecessary to repeat that fuller exposition here.

This change-over from a mental life that was merely experience-checked imagining to an analytical mental life aiming at new and better knowledge and leading on to planned and directed effort, is still in progress. It is the greatest change in the methods and nature of conscious life that has ever occurred. It is still only partly achieved. Over a large range of his interests man has still to acquire the habit of thinking with self-control and precision.

§ 2. *The Criticism of the Instrument of Thought from the Beginnings of Directed Thinking Onward; Nominalism and Realism; Experiment; The Renascence of Science*

The philosophers of the Athenian and Hellenic communities of the sixth, fifth, fourth and third centuries B.C. inaugurated the logic-restrained and question-guided thinking of the modern world. But, as we have said, it was a beginning only. It was not the whole stride that had to be made, and we must not exaggerate even while we recognize its essential significance. Man did not, at that time, fall suddenly into a perfected way of thinking. He sought precision. By no means did he attain it. Day cannot come without a dawn, but the dawn is not the day.

That age of intellectual vigour in Greece marks the breakaway from mythological imaginative interpretations, and it marks also the first repudiation of tradition. The Utopianism of Plato is the first announcement of man's ability to depart from tradition in his acts and institutions. The Science of Aristotle displays a realization of the need for, and the possibility of, attaining a growing orderly body of tested knowledge and directive ideas, for the use of our race. It was to be new and increasing knowledge. That widening departure from tradition is the fundamental subject matter of this book. We are only carrying out to-day the intellectual release that Athens began.

Let us state clearly the full importance of that release. The *Science of Life* deals fully with the appearance of *tradition* in human evolution, shows how it was at first a progressive innovation and how greatly it accelerated social development, how it dispensed with the slow attainment of hereditable characters through mutation and selection, and also how it is now giving place to a still swifter process of social adaptation, due to the systematic interrogation of fact, organized research, and *planned development* that was latent in the new way of thinking. This transition from tradition to deliberate planning which is now in progress, is at least as great an event in evolution as the transition from unassisted heredity to heredity-plus-tradition which carried man above the level of the brute. The man who orders his knowledge and thinks things out is as far above the natural man of impulse and traditional usage as the latter is above an ape which has not even tradition but only instinct. They represent three successive stages of vital adjustment.

The Hellenic world conceived and shaped the instrument for modern thought and prepared the human mind for that widening breach from tradition, that forward-looking attitude, to which it is now committed. But, outside certain fields where the need for observation and experiment was limited, Greek scientific achievements were, by our modern standards, small. Greece made only the first step towards effective knowledge. There were many more further steps to be made before even such mental efficiency as we can boast to-day was attained. The instrument of modern thought was invented and shaped in the Hellenic age, but it had still to be sharpened and relieved of many clumsy associations. A long succession of active brains had still to work upon that task—a task that is still far from completion.

Moreover, that bright beginning in the eastern Mediterranean was hampered, checked and arrested by unfavourable political and social conditions. The *Outline of History* tells how the small and scattered band of original thinkers, which constituted the whole intellectual life of the Hellenic world, was slowly swamped and stifled by the conservative traditions of Egypt and overwhelmed by the vast expansion, disturbances and collapse that constituted the history of Roman Imperialism. That first intelligentsia, the Hellenic intelligentsia, never arrived at any sufficient facilities for conducting experiments or exchanging and discussing observations and results. Indeed, it had a very insufficient sense of the need for multitudinous experiments. It was over-confident of this new process of logical thinking it had developed, and unsuspicious that the new method had its own peculiar dangers and pitfalls.

What were the imperfections of the new method of directed thinking? What was still unsatisfactory about logical reasoning as the classical world understood it?

That there was an unsatisfactoriness appears plainly in certain of the dialogues of Plato, but in a manner and with an application that does not fit in very conveniently to contemporary needs. The essence of the unsatisfactoriness that appeared was this: that there was a question how far words were *accurate*. Were words as true as material facts, or truer, or less true? If they were truer, then a logical conclusion was truer than an experience, and that, on the whole, was the classical assumption.

I write "on the whole" because this assumption was then already being questioned. It may be difficult for many minds to realize that any people have ever been disposed to think that words were truer than experienced things. But the fact is that not only have men in the past continually tended to treat words as more real than material facts, but that now, at the present time, men, you and I included, are tending to do exactly the same thing. We suspect and resist that tendency now, but many people have so far given way to it as to believe that in words they had a means of penetrating beneath experience and appearances down to profounder truths. The tangle between the One and the Many, between the Ideal expressed by the word and the Individuals assembled under the word, arises out of this disposition. It was only through the toilsome discussion and bickering of many generations of men in the later Middle Ages that the processes of this directed thought, which was and is still replacing the more primitive uncriticized flow of associations, were cured, to some extent, of its early disposition towards an independent arrogance, a false profundity and over-confidence, and recalled to a closer relationship to the verities of life. As briefly as possible we will put the bare elements of that great debate before the reader. He may then be willing to admit that those "Schoolmen" who wrangled through the centuries were doing a very indispensable work, too little appreciated by this contemporary world of ours—which indeed could never have existed without their wrangling.

Everybody has heard of this wrangling, of the great mediæval controversy between Nominalism and Realism, but the ordinary educated man, because of his insufficient and misleading education about such matters, is still all too ready to suppose that it was some extraordinary, remote, dry-as-dust conflict of pedants, that can have no possible interest for him. He thinks it was a dispute about some dead issue which has no possible bearing upon his life. He has not been told the truth of the business. That conflict has never really ceased because it has not yet been fought to a definite conclusion; it is still going on all about us under an endless diversity of masks and forms, and there is not a thing in our social, political and economic life that would not have been profoundly different if these controversies had never arisen.

The essence of this vast dispute between Nominalism and Realism which was already beginning in the Greek discussion between the One and the Many, and which is still far from a final conclusion, may be stated in a few paragraphs. Indeed, one may get very near the heart of the matter in a sentence. We have already said that there are three ways of thinking about words; one may think they are truer or less true than fact, or that they are *accurate* and fit fact exactly. For the Realist the word was truer than the experience; for the Nominalist the experience was truer than the word.

The human mind is a very imperfect instrument, just as the human eye is a very imperfect instrument. And just as the eye is prone to "optical illusions," so the human mind has its innate disposition to certain intellectual illusions. Chief among these is this disposition to trust to words, to names; the disposition, for example, to regard any unreal conception to which a name has been given, or any group of things to which a name can be given, as being thereby made actual and different from all other things. The mind trusts too much to the symbol or word it has adopted. The *name*, the *word*, which is man's implement, can easily become his master. He is disposed to believe that things that are called by the same name are necessarily all alike and altogether alike. He falls into that sort of acceptance very readily. He is always slipping into the error of confusing similarity with identity, and supposing that things that have one common quality or a few common qualities have all their qualities alike.

So he is apt to believe that all atoms or all herrings or all sheep or all Englishmen or all sovereign states, are exactly and in every detail alike because they are spoken of by the same word. By that word they are made one. He takes refuge from the infinite variety of existence in the *word*, which he can then reason and dogmatize about. He will say "all sheep" do this or "all Englishmen" do that —meaning that mostly they do. His untutored disposition is to treat the name of a group of things as though it expressed something fundamental and essential, and to ignore the endless variations that shelter under every common noun. This assumption that a name has something real and quintessential in itself, that there is an ideal and perfect sheep, for example, over and above all individual sheep, is the essence of philosophical Realism. The denial that a name is anything more than a label put upon an assembly of more or less similar but never identically similar things is the essence of Nominalism.

There is, we must note here, an unfortunate conflict between the common use of the word "realist" and its proper original meaning. The contemporary reader has to be warned of that difference in usage if he is not to misconceive all this section. In the great controversies of the Middle Ages, the Realists were those who followed this more natural but deceptive human tendency to treat names as expressing something more real than actual existences; while those who held that names were not in themselves real, that they were *only* names, labels just stuck upon things for our mental convenience and susceptible of infinite shifting and alteration, were called Nominalists. The Realist believed only in the reality of words and the general ideas they embodied; the Nominalist believed only in the reality of things and individual instances. The Realist believed that all individuals are imperfect specimens of the perfect "type"; the Nominalist ignored the perfect type. The mediæval Realist was what we should nowadays call an idealist, a Platonic idealist;

the Nominalist was the facty man.

This is evidently almost the exact opposite of our modern use of "realist" and "realism," and in order to keep this distinction before the reader's mind, we spell "Realism" here, when it means the philosophical teaching and not insistence upon "actuality," with a capital R. That vast necessary controversy that went on in the Middle Ages was essentially a struggle of the human mind to escape from the innate vice of Realism, from the phantoms, the delusions created in the mind by primitive uncorrected Realist thought, and to look directly and discriminately at things themselves.

"Very nice," says the modern Nominalist, after the most clenching deductions, "and now let us try if it is so."

Both sides in that huge wrangle went far and stated excessive cases. Roscellin, an extreme Nominalist of the eleventh century, for example, held that a name, a word, was no more than a *flatus vocis*, vocal wind. But from the time of William of Ockham onward (fourteenth century), and indeed from the time of Abelard (twelfth century) the recognition grew that names and classifications might carry more or less weight and convey more or less truth. Words had to be scrutinized. There might be false as well as true conceptions in the mind. Some words were truer than others, they implied a higher degree of similarity than others, but none were as true as fact. When every name, every word, was marked with a note of interrogation, the way of escape from Realism lay open.

To escape from Realism is to escape from hard classifications, from the harsh judgments, assurance, uncompromising attitudes and dogmas that arise from hard classifications, and to move towards qualified statements, the examination of individual qualified statements, the examination of individual instances, enquiry, experiment and careful verification.

Here we will not attempt to follow the fluctuations of that immense dispute. The practical defeat of Realism over large areas of human interest was obviously a necessary preliminary to the release of experimental science. You could not get men to look at reality until verbal Realism was abandoned. It was so much easier to deduce your beliefs from first principles than to go out to make observations, and according to Realist ideas it was a sounder process. The protest of Roger Bacon was the outcry of a Nominalist in a Realist age. The Realist still ruled completely in the universities and over the teachers for a century after his death.

It was Roger Bacon who was first to ascribe to experiment its proper importance in the pursuit and discipline of knowledge. It was he who first insisted clearly that logical processes must be constantly checked by facts. On that account we take him as we took Plato and Aristotle—as a landmark in human development. He serves to mark a further step in the escape of the human mind and will, from their original limitations. It was not so much what he did as what he said that gives him importance. His own actual experimental achievements amounted to barely anything at all. But he was almost the first human being to stress the supreme importance of verificatory experiment in the search for knowledge. He stands out as, in effect, insisting that no words could be trusted without the test of experiment.

His writings led straight to the scientific method of extending and using knowledge. One hears a great deal about the "scientific method" and it is often spoken of as though it were a distinctive method of thinking. But it is not a distinctive method of thinking, but only a distinctive method of using the logical method of thought already in existence, but of using it in a new spirit, a spirit of distrust. Your logic might prove that a thing should be so; your experiment then had to prove that it was so. "Observe, try, record, speculate logically, try out your speculation, confirm or correct, *communicate to other investigators, hear their communications, compare, discuss logically,* establish and so onward"; this, for all practical purposes, is the method of science. Apply as occasion arises. Eschew all *a priori* methods, for you do not know enough about your brain to trust it to work without this constant experimental checking. Check it by other brains, but above all check it by facts. Distrust every term, every name, you use. Logic is very serviceable as an aid to judgment but not as a final judge. All the terms you use *fit loosely on fact.* That is the key persuasion behind the experimental method. Keep trying back to fact. Such was the working scientific method of the nineteenth century, that age of material progress, and it is still the working scientific method at the present time. It is a repudiation of all philosophy that is not perpetually verifying its propositions.

Upon that working philosophy, upon that insistence that every assertion must be checked by fact and by the scrutiny and corroboration of other eyes and ears and minds, all the material triumphs of the scientific worker during the last century have been made. He sets himself to master the things at hand as thoroughly as possible. That is his essential and personal job. If there are limitless implications in these immediate things, he believes that they will unfold themselves and become plainer as his work proceeds. But he will not anticipate such progressive revelations. He will not trust his mind except when it remains in the closest touch with fact and with the concepts of his fellows. He will not tolerate the philosophies that merely project the peculiarities and obsessions of the human mind upon the universe, and declare that this is Truth. The rôle of philosophy from the point of view of the scientific man is not the attainment of wisdom but the perpetual accompaniment and criticism of man's thinking—to avoid follies and remove obstacles.

The detachment of the human mind from its Realistic predispositions remains incomplete. Mankind still believed in the fixity of animal and vegetable species—which were supposed to vary about a perfect type—until less than a century ago, and in the identical similarity of atoms until a quarter of a century ago; and in the world of international politics the Realist way of thinking holds almost undisputed sway at the present time. That intellectual error lies at the root of the greatest dangers that threaten our race. Men's hearts may be in the right place, but their poor heads are still befogged by the magic of names. Plainly a man who takes the Nominalist way and regards such a word as "France" as merely a name covering a great area of country, climatic and social associations, and about forty million human beings of very diverse kinds (numbers of them not even speaking French), will regard international politics from an entirely different angle from a Realist who finds in the word France something more real and vital than any single individual or thing that contributes to the ensemble of that idea. "Russia" is another magic term of this sort for the Realists; "Mother India" again, or the "Old Country," whichever it is. Since we do not teach the significance of these words "Nominalist" and "Realist" in our schools, nor give any sort of training in analytical thinking, we are Nominalists or Realists as our mental temperament or luck may determine, and the Nominalist and Realist of contemporary life, all unaware of this difference in the very elements of their thought, find each the other stupefyingly obtuse. Each cannot see what is the matter with the other's mind. The Realist "patriot" calls his brother Nominalist "traitor" or "cosmopolitan scoundrel," and the like, and is amazed that he does not wince; the Nominalist humanitarian calls the Realist, obdurate dogmatist or romanticist and accuses him of a perverse taste for contention and blood.

At a considerably higher level we find the contemporary mathematician who has still to learn the real meaning of "experimental verification," and who is habituated to treating the schemes of concepts in his brain as truer than fact, at odds with the modern biologist. Still constrained in the logical net, he shakes his head at the "unphilosophical" ease of the latter's mental movements. He objects to conclusions that are not final and exactly proved. He has not learnt to rest in a provisional conclusion, and clings to the delusion that purely symbolic processes can win truth from the unknown. His symbolic processes never do win truth from the unknown, but he fancies that they justify an attitude of disapproval towards the pragmatical acceptances of practical science. But in the long run perhaps even the mathematicians will become scientific.

The Nominalist emancipation of the human mind proceeds slowly, but it proceeds; the boundaries of once hard classifications become transparent and manifestly provisional. The discovery of Evolution, the realization, that is to say, that there are no strict limits set to animal and vegetable species, opened the whole world of life and its destiny to Nominalist thinking. The realization by the world of mathematical physics that the universe can be represented as a four-dimensional universe of unique events has abolished the conception of a quantitative equivalence of cause and effect and made every atom unique. Only the indifference of school and college to current thought has prevented every thinking person from becoming a Nominalist by the present time.

§ 3. *The Practical Nature of Renascent Science*

Two fundamental ideas came with the experimental method in the renascent world of the later Middle Ages, to qualify, extend, and empower the first great releases of the Hellenic period. One of them is the *changeableness of substances* leading on to the possibility of changing them, and the other is the possibility of *deliberately releasing power.* Neither of these ideas is in evidence in Hellenic science. They were latent in it, perhaps, but they were not in evidence. Their appearance in effective action marks a profound difference between the Old World and the New. The deliberate "Conquest of Substances" and the deliberate "Conquest of Power" are entirely characteristic of our modern world.

There were deep enquiries into the nature and constitution of matter in the ancient world, such as the wonderful guesses of Lucretius, but these were speculative exercises of the mind, prompted by the desire to explain, rather than the passion for effective knowledge. The science of Aristotle is largely descriptive. The herbalist sought practical knowledge, but to the Old-World mind substances were what they were, just as plants and animals were what they were. You knew about them, but you did not probe into them. And neither was there research for power. Curious mechanical toys were made—and there at the curious stage they remained. There was little experimental work, and the philosopher did not deign to share in and scrutinize the practical secrets of the metal worker and suchlike artisans. Archimedes would not have the construction of his practical contrivances recorded. They were beneath his dignity as a philosopher—mere artisan tricks. The highest aim and the only honoured aim of that earlier science was to know.

It is only as the obscure, secretive science of the late Middle Ages emerges to publicity and discussion that we find these new conceptions of *interference with substance* and the *release of force* in action. The alchemist we discover looking for the elixir of life and the transmutation of baser metals into gold. From alchemy chemistry developed into "iatro chemistry," the chemistry of medically useful substances. All the ancient aloofness of the philosopher gentleman had disappeared by the dawn of the new time. Roger Bacon is full of practical promises, they made the substance of his message, and Francis Bacon died through a chill contracted when making a crude experiment upon the preservative use of cold. He got out of his coach to stuff snow into a fowl.

The science of this new phase was concerned not with the essential nature of things as the old had been, but with the properties of things and what you could do to them and with them. It was more modest because it did not set itself to explain, and yet it was bolder because instead of merely accepting and describing, it set itself to use and alter. It did not pontificate about fact; it grappled with fact. It was philosophically more modest and practically more courageous. It sought practical ends and presently, and almost inadvertently, it found itself penetrating far more profoundly into the nature of things than the exalted philosophers of the Hellenic world had ever been able to do. But that profounder knowledge came by the way; it was found by the wayside to actuality. Science did not even stoop to conquer. It stooped to practical things and conquest ensued.

This modesty of approach and this bias towards practical issues may have been forced upon renascent science by the religious intolerance of Christendom. If so, there is something to be said for intolerance. The Hellenic philosophers had nothing to forbid their seeking fundamental knowledge, but in the late Middle Ages scientific enquiry could only be released by that compromise of the later schoolmen which distinguished sharply between "spiritual" truth which was the *higher truth*, and rational truth, the everyday truth of normal experience and the secular mind. In that way the reconstruction of astronomical ideas which has gradually released the human imagination from an earth-centred universe to the immensity of space, and the realization of organic evolution that has opened to man the limitless vistas of time, have been possible without a conflict to the death between science and religion. There have been disputes and discussions of a very far-reaching kind, there have been forced recantations like Galileo's and martyrs like Bruno, there have been skirmishes in the Garden of Eden and quarrels about the Gadarene swine, but the combatants have never finally clinched. At the close of the nineteenth century science worked upon lines that implied a conception of the universe which was rigidly fatalistic, side by side with the picture of free-will, unqualified initiative and moral responsibility, presented by the religious teacher. It was an intellectual incompatibility which did not interfere very greatly in the steady extension of the multitude of substances that were being made available for human purposes or in the continually increased utilization of extraneous power. Science worked and religion attended to the immaterial needs of mankind.

§ 4. *Ultimate Truths Are Outside the Diagrams of Experimental Science*

In recent years very extensive readjustments have been made in the general formulæ which the man of science has used to simplify and systematize his facts. These readjustments have occurred mainly in the world of physical science; they have affected the steady advance of biological and social science very little. It is the professor of physics who is most concerned. The philosophical concepts that have served to guide and sustain his enquiries hitherto have been, so to speak, under repair. He has had to alter his general diagrams.

The reader will have heard endless echoes and repercussions from these enquiries into philosophico-scientific technique, even if he has not deliberately studied them, and so it is well to explain how far they concern us and how far they do not concern us in this work.

Some recent experiments and observations have jarred heavily with the general philosophical ideas that have hitherto satisfied and served the scientific worker. His diagrams have had to undergo a considerable revision. They were much too naïve and "obvious." In certain fields he has had to question the essential reality of that framework of space and time in which he—in common with the man in the street—has been wont to arrange his facts. He has had to scrutinize the ideas of time and eternity afresh. He has been brought to consider Euclidean space as only one of a great number of theoretical spaces, and to replace it by other and subtler concepts of space that seem more compatible with these recently observed facts. The old issue between predestination and free-will has in effect been revived in terms of mathematical physics. Is the universe a fixed, rigid time-space system, or has it movement in still other dimensions? Is it a continuous or an intermittent universe? The mere asking of such strange questions is very exciting to the speculative mind. But they do not affect the practical everyday life, either of the individual or of mankind, and we note these interesting developments of modern thought here as fascinating exercises for the intelligence outside our subject altogether.

It may be that we exist and cease to exist in alternations, like the minute dots in some forms of toned printing or the succession of pictures on a cinema film. It may be that consciousness is an illusion of movement in an eternal, static, multi-dimensional universe. We may be only a story written on a ground of inconceivable realities, the pattern of a carpet beneath the feet of the incomprehensible. We may be, as Sir James Jeans seems to suggest, part of a vast idea in the meditation of a divine circumambient mathematician. It is wonderful exercise for the mind to peer at such possibilities. It brings us to the realization of the entirely limited nature of our intelligence, such as it is, and of existence as we know it. It leads plainly towards the belief that with minds such as ours the ultimate truth of things is for ever inconceivable and unknowable. It brings us to the realization that these theories, the working diagrams of modern science are in the end less provisional only in the measure of their effective working than the mythologies and symbols of barbaric religions.

But it does not give us any present escape from this world of work and wealth and war. For us, while we live, there must always be a to-morrow and choice, and no play of logic and formulæ can ever take us out of these necessities. To be taken out of these necessities would be to be taken out of existence as we know it altogether.

It is impossible to dismiss mystery from life. Being is altogether mysterious. Mystery is all about us and in us, the Inconceivable permeates us, it is "closer than breathing and nearer than hands and feet." For all we know, that which we are may rise at death from living, as an intent player wakes up from his absorption when a game comes to an end, or as a spectator turns his eyes from the stage as the curtain falls, to look at the auditorium he has for a time forgotten. These are pretty metaphors, that have nothing to do with the game or the drama of space and time. Ultimately the mystery may be the only thing that matters, but *within the rules and limits of the game of life*, when you are catching trains or paying bills or earning a living, the mystery does not matter at all.

It is this sense of an unfathomable reality to which not only life but all present being is but a surface, it is this realization "of the gulf beneath all seeming and of the silence above all sounds," which makes a modern mind impatient with the tricks and subterfuges of those ghost-haunted metaphysicians and creed-entangled apologists who are continually asserting and clamouring that science is dogmatic—with would-be permanent dogmas that are for ever being overthrown. They try to degrade science to their own level. But she has never pretended to that finality which is the quality of religious dogmas. Science pits no dogmas against the dogmas of the ghost worshippers. Only sometimes, when perforce science touches their dogmas, do these latter dissolve away. Science is of set intention superficial. It touches religious dogma only in so far as religious dogma is materialistic, only in so far as religious dogma is a jumble of impossible stories about origins and destinies in space and time, a story pretending to a "spirituality" that is merely a dreamy, crazy attenuation of things material. And even then does it touch these dogmas only because they involve magic irrational distractions, interferences and limitations of the everyday life of man.

I wish that there was a plain and popular book in existence upon the history of scientific ideas.[*] It would be fascinating to reconstruct the intellectual atmosphere that surrounded Galileo and show the pre-existing foundations on which his ideas were based. Or ask what did Gilbert, the first student of magnetism, knew, and what was the ideology with which the natural philosophers of the Stuart period had to struggle? It would be very interesting and illuminating to trace the rapid modification of these elementary concepts as the scientific process became vigorous and spread into general thought.

Few people realize how recent that invasion is, how new the current diagram of the universe is, and how recently the ideas of modern science have reached the commoner sort of people. The present writer is sixty-five. When he was a little boy his mother taught him out of a book she valued very highly, *Magnell's Questions*. It had been her own schoolbook. It was already old-fashioned, but it was still in use and on sale. It was a book on the eighteenth-century plan of question and answer, and it taught that there were four elements, earth, air, fire and water.

These four elements are as old at least as Aristotle. It never

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[*] But *Man and His Universe*, by J. Langdon Davies, is good, readable and suggestive, and Ginzburg's *The Adventure of Science* also comes very close to my wish. I may add Holmyard's *Chemistry for Beginners* and Alexander Findlay's *Spirit of Chemistry* as agreeable books for the general reader who would like to expand the matter of this necessarily very brief section. Finally as the proofs of this book pass through my hands, my attention is called to a still closer approximation to my desire in E. A. Burtt's *Metaphysical Foundations of Modern Science* (1925).

occurred to me in my white-sock and plaid-petticoat days to ask in what proportion these fundamental ingredients were mixed in myself or the tablecloth or my bread and milk. I just swallowed them as I swallowed the bread and milk.

From Aristotle I made a stride to the eighteenth century. The two elements of the Arabian alchemists, sulphur and mercury, I never heard of then, nor of Paracelsus and his universe of salt, sulphur, mercury, water, and the vital elixir. None of that ever got through to me. I went to a boys' school and there I learnt, straightaway, that I was made up of hard, definite molecules, built up of hard definite indestructible atoms of carbon, oxygen, hydrogen, nitrogen, phosphorus, calcium, sodium, chlorine, and a few others. These were the real elements. They were shown plainly in my textbook like peas or common balls suitably grouped. That also I accepted for a time without making any fuss about it. I do not remember parting with the Four Elements: they got lost and I went on with the new lot.

At another school and then at the Royal College of Science I learnt of a simple eternity of atoms and force. But the atoms now began to be less solid and simple. We talked very much of ether and protyle at the Royal College, but protons and electrons were still to come, and atoms, though taking on strange shapes and movements, were intact. Atoms could neither be transformed nor destroyed, but forces, though they could not be destroyed, could be transformed. This indestructibility of the chameleon of force, was the celebrated Conservation of Energy, which has since lost prestige, though it remains as a sound working generalization for the everyday engineer.

But in those days, when I debated and philosophized with my fellow students, I was speedily made aware that these atoms and molecules were not realities at all; they were, it was explained to me, essentially mnemonics; they satisfied, in the simplest possible arrangement of material models and images, what was needed to assemble and reconcile the known phenomena of matter. That was all they were. That I grasped without much difficulty. There was no shock to me, therefore, when presently new observations necessitated fresh elaborations of the model. My schoolmaster had been a little too crude in his instructions. He had not been a scientific man, but only a teacher of science. He had been an unredeemed Realist, teaching science in a dogmatic Realist way. Science, I now understood, never contradicts herself absolutely, but she is always busy in revising her classifications and touching up and rephrasing her earlier cruder statements. Science never professes to present more than a working diagram of fact. She does not *explain*, she *states the relations and associations of facts as simply as possible.*

Her justification for her diagrams lies in her increasing power to change matter. The test of all her theories is that they work. She has always been true, and continually she becomes truer. But she never expects to reach Ultimate Truth. At their truest her theories are not, and never pretend to be, more than diagrams to fit, not even all possible facts, but simply the known facts.

In my student days, forty-five years ago now, we were already quite aware* that the *exact* equivalence of cause and effect was no more than a convenient convention, and that it was possible to represent the universe as a system of unique events in a spacetime framework. These are not new ideas. They were then common student talk. When excited journalists announce that such intellectualists as Professor Eddington and Professor Whitehead have made astounding discoveries to overthrow the "dogmas of science," they are writing in sublime ignorance of the fact that there are no dogmas of science, and that these ideas that seem such marvellous "discoveries" to them have been in circulation for more than half a century.

No engineer bothers about these considerations of marginal error and the relativity of things, when he plans out the making of a number of machines "in series" with replaceable parts. Every part is unique indeed and a little out of the straight, but it is near enough and straight enough to serve. The machines work. And no appreciable effect has been produced upon the teaching of machine drawing by the possibility that space is curved and expanding. In this book, let the reader bear in mind, we are always down at the level of the engineer and the machine drawing. From cover to cover we are dealing with practical things on the surface of the earth, where gravitation is best represented as a centripetal pull, and where a pound of feathers weighs equal to a pound of lead, and things are what they seem. We deal with

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* See, for example, my own undergraduate essay in the *Fortnightly Review*, July 1, 1891, "The Rediscovery of the Unique"; and see also L. Silberstein upon "The Time Machine," 1894, in his *Theory of Relativity* (1914), p. 134

the daily life of human beings now and in the ages immediately ahead. We remain in the space and time of ordinary experience throughout this book, at an infinite distance from ultimate truth.*

§ 5. *The Organization of Modern Research*

Let us consider how this collection of working diagrams up to date, this practical thing, Science, is perpetually being added to and perpetually being clarified and made more serviceable.

There was a time not so very long ago when an isolated man of independent means might still conduct investigations of primary importance and make great additions to knowledge or profound changes in ideology single-handed. A man like Cavendish, the great chemist, or the Abbé Mendel, could work on his own resources and could leave notes and observations behind him to lie undeveloped and disregarded for a long time. But now we think a great deal more in each other's minds than we did. It is often difficult and sometimes impossible to trace the authorship of modern key phrases and words and terms. Who, outside a small specialized world, knows, for example, who first used "genes" or "auto-suggestion" or "metapsychics" or "values"? No doubt the answer is to be given in each case, but few of us trouble about the answer. The new term is thrown out, and suddenly we are all using it. We do not want to be bothered about questions of copyright. Patent rights in a new terminology are no longer recognized. A score of men turn a corner at about the same time and at once indicate their sense of a new direction by the same inevitable phrase that no one had ever dreamt of using before.

To-day, in an increasing number of subjects, teamwork research prevails, and in many it is the only possible method. In the *Science of Life* the rapid production of valuable results by the teamwork in genetics under Morgan in New York is described.

A history and discussion of the social and economic basis of scientific work from the very beginnings of scientific thought would be profoundly useful Where did scientific questioning really

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* Our discussion of the relations of science to human life, philosophy and belief in the four preceding sections has been necessarily very bare and swift. The reader who would like a longer and fuller treatment of these questions will find it in W. C. D Dampier-Whetham's *History of Science and Its Relations with Philosophy and Religion.*

begin? The priesthoods of the early civilizations had a considerable accumulation of knowledge. How had it been accumulated and reported? It seems to have undergone a slow but steady progressive development. Gradually the archæologists, and especially the Egyptologists, are disentangling the material to answer that question. For the last century or more workers, in Egypt especially, have been getting together and cataloguing and classifying the material for the understanding of these remote mental processes, but now, and with the inspiration of a psychology suddenly become boldly speculative and analytical, we are more and more able to realize the current assumptions and reconstruct the thought of past periods.

I doubt if the Egyptians had any idea of research. I suspect that even a very intelligent Egyptian or Sumerian priest supposed that everything was known that could be known, even if he and those about him did not know it all. He had no suspicion of limitless seas of knowledge accessible but unexplored. For him there existed already—Wisdom. All one had to do was to learn and learn, to seek out mighty Sages and learn more. And if he observed something that he had never heard of before, then I suppose he put it on record not as anything new but as a mere provisional replacement of some part of the mosaic of Wisdom that had got mislaid. I doubt if any Egyptian priest, however original, ever thought in the form of fresh discovery. Even when they were most original the ancients were always, they thought, restoring Wisdom. They were, they imagined, in conflict not with virgin ignorance but with corruptions.

Knowledge and skill, conditioned by such views, advanced slowly, backing forward and bowing to the past. Maybe that here or there a man had a momentary glimpse of the limitless seas of things still unknown that lay outside of and encompassed Wisdom—that Wisdom knew nothing about. But not for long did that glimpse last. Such a thought, if it occurred at all, must have traversed the mind of an Egyptian priest, very much as a terrified mouse dashes across a room. It was there. It was gone. Even to-day the intelligent visitor to Egypt, walking through her long colonnades, recalls something of the fixed recurrence, the finality, to which the world of the great dynasties had attained. Everything was known, they supposed, and across the dark river waited Anubis the Accuser, Horus the Saviour, and—if the scales did not condemn the pleading soul—eternal bliss with Osiris, stereotyped also for ever. That was life. That was all.

It seems plausible to suppose that the first scientific questionings began where traditions came into conflict. My own coarse guess is that the southward swirl of the Aryan-speakers across the Asiatic and Mediterranean civilizations did much to loosen the roots of old ideas, that the clash of strange languages led to a new curiosity about meaning and so to logical analysis, and that the development of a class of independent, prosperous, but not too opulent people with leisure made the play of doubt effective. They sat about and talked and reasoned a little; they wrote, and copies were made of what they wrote. They began to ask such questions as, "How do we know what we know?" Much of that discussion was forgotten or lost again. When at last the story of enquiry and record is fully traced out it will seem marvellous how narrow and precarious were the first springs and rivulets that have swelled to the science of to-day.

What was the first dawn of associated scientific work? The Museum at Alexandria, perhaps. All associations in the ancient world had to be religious associations, or they were regarded as dangerous conspiracies. The Alexandrian savants therefore dedicated themselves to the Muses. They were patronized by the Hellenic Pharaohs. What well-nigh imperceptible drops in the general flood of contemporary human acceptance were these Hellenic sages who set out upon such enterprises as the measurement of the globe! How flimsy was the thread of occasional and precarious letters that linked minds in Alexandria with kindred minds in Athens and Syracuse!

The renewal of the scientific process in mediæval Europe is often ascribed rather absurdly to the dissemination of the Greek literature, after the fall of Constantinople to the Turk. But science died in Imperial Rome with all that Greek literature at hand. Some necessary freedom or protection had disappeared. Nobody was, in fact, left free to care for it. The revival was due much more to the reappearance of certain social types, and particularly of *secure, freely thinking, independent people*, people of "means," stimulated by, but not absorbed in public responsibilities. They could give curiosity play and amuse themselves with dreams of magic discovery. Half-seriously and a little furtively these fortunate amateurs took up the search for the secret of transmuting metals and the mysteries of longevity. We have noted the new streak of practicality in the science of the Renascence. The "curio" came before the museum; the pottering odd experiment before the definite enquiry.

Embryonic modern science was closely mixed up with art. Philosophy wrangled. Art observed. Dürer and Leonardo were scientific pioneers. The universities droned along blindly with the oral teaching of traditional wisdom; they were on the side of tradition. Modern science owes few of its initiatives to them.

Mercantile motives and the vast raids of the Mongols set the process of geographical exploration at work again. It had been suspended from the days of the Roman ascendency. Its effect in effacing the delusion that everything was known extended far beyond the geographical field. The unrest and doubt that spread out from this Mongol thrust was probably much more important than the Greek stimulus. The revival of Greek studies at the Renascence did not so much start new ideas in men's minds as confirm and stimulate what was already stirring.

The difference between the mentality of a sixteenth-century gentleman of intellectual tastes and a mentally vigorous Egyptian priest must have rested primarily in the relative realization by the former that there was a limitless, accessible circumambient unknown. There the sixteenth-century gentleman was in advance of the priest. But also he was intensely individualistic, and there he seems to us nowadays to have been less "modern." The priest had a sense of belonging to an organized system; albeit it was a tradition-preserving system. The founders of modern science worked for a time almost independently. They met first in the early academies: the Academia Secretorum Naturæ of Naples, 1590, suspected of the black arts and closed by the Pope; the Academia dei Lincei, of which Galileo was a member, 1603; the Academia Naturæ Curiosorum of Madrid, 1657; the Académie des Sciences, incorporated in 1666 after thirty years of informal meetings (including Descartes, Gassendi, Pascal); the London Royal Society (1662, after informal meetings dating from 1645), and presently a variety of specialized scientific societies.* But they assembled under no sense of obliga-

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* M. Ornstein's *The Rôle of the Scientific Societies of the Seventeenth Century* (1928) may interest the reader who would like more detail here.

tion, just out of fellow feeling, for the social gratification of their curiosity, and perhaps also for the sense of a possible need for mutual protection against the hostility of the traditional. The greatness of Bacon's *New Atlantis* lies in the clear recognition by its author of the need for co-operation in research.

The first modern co-operation in research seems to have been made under the auspices of royal and wealthy persons, to form collections and horticultural and zoological gardens too expensive for a private purse. There the royal and wealthy of the seventeenth century recall the memory of Asoka and the Ptolemies. To begin with, laboratories were individual and private. The first men to earn a living by experimental science were, I suppose, the assistants of scientifically inclined gentlemen. They emerged to distinction like the groundsmen and professionals in the games of cricket and golf. Until they could teach their employers. . . . Then gifted young men began to be "discovered" and assisted in their own investigations, and research institutions appeared. The accumulation of facts and generalizations presently led to public lectures and movements for the diffusion of scientific knowledge.

The material for this story is still scattered in hundreds of biographies and collections of letters. It is all very recent, an affair of three centuries at most. But when it has been collected and arranged the compilers will have done their task ineffectively if they do not display a steady change of attitude on the part of those who were engaged upon that accumulation, towards the knowledge they had procured and tested.

Only in moments of insight and exaltation did the curio-collecting nobles and gentlemen of the sixteenth and seventeenth centuries realize this mighty new directive system they were evoking. This amusing and surprising little pet creature, this Natural Philosophy of theirs, was to grow into a dragon that would sustain the world, but of this they had no idea. For the most part science was a toy or an ingenious way of discovering new money-making activities, and presently it became a useful weapon for teasing the parsons. Or it aroused wonder. By imperceptible degrees we shall find the idea of scientific research as an important public function entitled to systematic support, and the associated idea of science as a devotion and a primary end in life, creeping into the record. Science ceased to be a recreation and became a pursuit. These new views about the importance of science have arrived very recently; within the lifetime of many who are still living.

Such stories as that of the Smithsonian Institution in Washington, of the Institut Pasteur, of the London Royal Institution, and of the Rockefeller group of endowments, would repay a careful scrutiny. They would reveal progressive stages in which men say more and more distinctly, "This Science is a great and mighty business." From such beginnings followed the progressive public organization of research.

The activities of the gentlemen who launched Natural Philosophy upon the world, needed to be supplemented by work of a coarser type before it could realize its vast potentialities. There were practical men, mostly millwrights and often of no education (Brindley could scarcely read and could write only with difficulty), who understood the pressing needs of the day and the practical difficulties in the way of overcoming them far better than the learned. They experimented in a crude practical way. To their help came some Natural Philosophers (Rennie and Smeaton were F. R. S.) and also some military engineers bringing traditional skill of a certain kind. Out of this contact and collaboration arose the civil engineers. The civil engineers bridged the gap between pure science and practical application; they linked the toy with the needs.

Scientific research is still in its prentice stage. It is still undergoing rapid change and development, and still greatly encumbered with military, naval, and other patriotic entanglements. Its organization for intercommunication is complex and imperfect. The Institute for Intellectual Co-operation at Paris, with Madame Curie as instigator, has directed its attention to this latter group of problems—I know not with what energy, resources, or effect. Organized world-wide research is still a promise rather than an achieved reality, and yet every year the astounding harvest of science and invention increases in mass and length and breadth.

It is interesting to glance at the relations between the scientific process and the older and newer universities of the world. Belatedly those venerable seats of learning which preserve the university tradition in its greatest purity gave their recognition to the new knowledge and, as far as they could, made it amenable to the established routines of syllabus and oral lecture, note-book and examination. They did not receive it humbly; they tried to annex it and assimilate it to their ancient concepts of learning. They did all they could to give it a quality of "scholarship." Enquiry was taught as far as possible as if it were traditional Wisdom. Chairs were set up for this and that, the boundaries of "subjects" were marked out, subjects that could, in fact, coalesce or split into a score of fragments in a year or so, and "degrees" were instituted in science just as they had been for centuries in the "fixed" subjects of erudition. The universities conferred "degrees" of Bachelor, Master and Doctor of Science; that is to say, bachelors who knew some, masters who knew most, and doctors who knew all. They arranged for the young to pass from the innocence of the first year undergraduate to the complete and final knowledge of the robed and hooded Doctor. He was then to be considered a finished scientific *scholar*. Scientific men were appointed to professorial chairs, and the universities, by an insistence upon oral teaching and administrative duties, sought to wean them from too sedulous a pursuit of research.

Only very reluctantly would these venerable institutions recognize the primary importance of research and the essential insignificance of scholarship to the man of science. Abraham Flexner, in *Universities, American, English and German*,* shows how much leeway modernization has still to make up. The constant fluctuations and extensions of the scheduled sciences, the perpetual eruption of crude *new* matter, worried the learned mind extremely and are still a cause for reproach on the part of scholars. They complain that science never really knows its own mind. It is perpetually correcting itself, perpetually superannuating its generalizations, never achieving a classical finish in its statements, never becoming Tradition. . . .

Slowly they are learning better now. University science becomes more and more scientific. The grants, the endowments and workers multiply. The science side grows ever greater and overshadows "scholarship" more and more. Knowledge is no longer despised because it is new, nor revered because it is mellow.

Scientific research in a review of human activities must be regarded not only from the point of view of a collective function, but also from the individual's point of view. Research work in itself

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* Quoted in *Nature*, April 18, 1931, p. 543.

becomes a career nowadays. It is clear that if the progressive development of human society is to continue, there must be a steady increase in the proportion of scientific workers to the total population. Very little attention has been paid to the social types and classes from which these workers are now drawn and the spirit in which they approach their unending co-operative task.

Scientific research is the modern form of the religious life It gives courage and a fundamental serenity. It is the securest refuge from the distresses of the human soul. The laboratory becomes the pathway to great adventures and limitless service. Its interrogations may send off men and women to every part of the world and direct them to the strangest experiences. Its pay and endowment are the least of its rewards.

But we are anticipating issues that will be better developed at a later stage. Let us turn now to the practical consequences of the scientific scrutiny of human conditions. The main practical sciences of the eighteenth and nineteenth centuries were chemistry and physics; the study of *substances*, that is, and the study of *force and movement*.* The one has led to a vast increase in the materials used in social life; the other to a systematic conquest of natural power.

§ 6. *The Conquest of Substances*

It would be a fine large task in itself to compile a great book, a Book of Substances, giving a really full and orderly record of the subjugation of matter to human needs, a review of all the stuffs out of which Man shapes the tools, implements, machinery, clothing, furnishing, housing, bridges, all the impedimenta indeed of our civilization. It would tell how man has passed from the flint to stainless steel and the sterilized scalpel, and from the walls of the rocky cavern, or a shelter of tree branches and leaves, to towering steel-framed buildings of reinforced concrete. Man was once an animal which picked up things by luck and took them and used them for what they were; he has become a planning creature, making and shaping objects more and more after his heart's desire.

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* Under chemistry we here put botany, which was at first not so much a biological study, a study that is of *living* things, as a systematic development of the lore of the herbalist, with a view to the recognition of plants and the use of plant materials.

That in brief would be the theme of that unwritten book.

Such a Book on Substances would open with a résumé of the materials used by the earliest men we know. The list would be a brief one. Some of the Hominidæ below the human level may have made a free use of sticks and unshaped stones, and may have already begun the shaping of flints. Animal substances, tusks, teeth and bones particularly, and skins, with some rude anticipations of leather-dressing, were added to these primary elements of the human equipment, and also clay, as a pigment to smear and as a substance to mould and dry. Vegetable fibre began to be twisted and woven. The first traces we have of *Homo sapiens* show him at this stage. The early Neolithic people had already a pretty taste in stones and were finding gold and setting a high value on it. Mining began before the Neolithic period. Palæolithic peoples mined for flints. Their workings are to be found in many places.

At first metals were only known through chance finds of gold and copper and meteoric iron, and then came the discovery of how to reduce certain metals from their ores. The first metallurgists worked in copper and bronze, and then came iron. The furnace improved. The furnace opened the way to glasses and enamels. A large field of knowledge, still rapidly growing, would have to be explored and summarized for this history of human materials. The Deutsches Museum at Munich gives models of primitive mines and the hearths and furnaces of savage people. It shows, in a charming model, negroes smelting iron ore. It gives a series leading up to the blast furnace. It unfolds in an illuminating series of exhibits a complex stream of stories about metal-winning—for every metal has its own history. The furnaces tower up, their interiors blaze more and more blindingly, the conquered and chastened metals pour more and more obediently to the casting.

All these advances, if one traces them carefully and intelligently, were prettily interdependent. One step here depends on the completion of a quite different step there. Ancient biology, for example, was greatly retarded in its development by its unawareness of the possibilities of magnification by properly shaped glasses or globular water flasks. It never suspected animalculæ therefore. Steel was known, iron was known, but neither was handled in large masses, and so the ancient world knew of steam only as the moving force of curious toys. The simple and obvious idea of railways which must have occurred to road makers again and again could find no material for its effective realization in the ancient world. A sort of rails—stone wheel tracks—are found in such excavated Roman cities as Pompeii and Pæstum. At that point the railway idea sat down, baffled. It had to wait a couple of thousand years before the rolling mill could turn out iron rails.

This History of Substances we have imagined, would go, comparatively speaking, at an ambling pace even up to the opening decades of the nineteenth century. Man's building operations at that time were still determined by the properties of a few building stones and a few types of mortar and cement, his clothing was either natural wool or silk or cotton, his dyes were "natural" dyes, his list of metals and alloys had hardly grown since the Roman Empire, and his steel was a kind of hard iron. And then came novelties. He began to work iron and steel upon a larger scale. The use of coal in metallurgical operations assisted that. That again led to a control of steam power. At the great museums of South Kensington and Munich the relationship of the development of the steam engine to a large handling of iron and steel is manifest. *Puffing Billy,* that early locomotive, is built up of a patchwork of plates of iron bolted together. It has become almost comic in its clumsiness to modern eyes. The relatively large modern engines are built up of castings, many of which would outweigh the entire *Rocket* or *Puffing Billy.* The first *Puffing Billy*—there were several engines of that name—weighed three tons without fuel or water, and with four wheels it broke the cast-iron rails provided for it and had to have the load redistributed over eight wheels. (The vanadium high-test cast-steel frames of the electric locomotives recently built for the Norfolk & Western Railway, U.S.A., weigh nearly 9.8 tons.) Side by side with the name of Watt, the name of Wilkinson the ironfounder should be remembered. The one could not have developed his ideas without the other.

Tinplate and coal gas were other cardinal events in the reawakening phase of human affairs. Rubber, wild rubber, crept into trade and industry, an unimportant stuff at first, destined to become a gigantic interest. In my childhood you rubbed out pencil marks with it. It had little more importance than that. Petroleum was a considerable find that also falls within the last seventy years.

Towards the middle nineteenth century the tempo of the narrative in our Story of Substances would quicken perceptibly. New metallic elements were being investigated; new alloys tried. Rubber began to be put to new uses and mixed with this and that. Such artificial substances as vulcanite and ebonite, combinations of raw rubber and sulphur, were being made and tried out for all sorts of purposes. The idea of artificial substances inspired a growing multitude of patentees. The deliberate conquest of substances was being undertaken. Every day new substances were being discovered and led into the factory.

The headlong substitution of "made" materials for "natural" materials during the last sixty or seventy years is an extraordinarily important fact in this present summary. At the opening of the scientific period, man was still going humbly and submissively to the rock or the plant or the sheep or the silkworm and taking what was given him as the directive and limiting conditions of the building or weaving. Now he makes his pastes and pulps into whatever texture or fibre he needs. Once steel was steel, a rather uncertain but powerful substance. Now, as we will tell later, there are hundreds of kinds of steel, and each knows precisely what is expected of it, and in understanding hands behaves accordingly. An array of once undreamt-of new metals has come in to enrich the resources of metallurgy.

In order to exhibit this array with anything resembling completeness, a sedulous canvass of great groups of industry would have to be made. So much novelty is continually being poured into industrial life that if we were to be up-to-date we should have to go to the fountain-heads. And also we should have to take stock of all the new raw materials, formerly unused, which are the basis of this ever-increasing array of made and prepared substances.

But it is possible to sketch out one or two striking developments that have occurred in the list of industrial substances during the last century, and this shall be done in the next section. That Book of Substances I have just projected for an actual encyclopædic *Science of Work and Wealth* would be a filling up of the gaps and an amplification of the particulars of this and the following section.

But it would go further. It would take up the question of quantities, a thing we cannot even begin to do here. To make the story complete there would have to be an estimate of the visible and probable supplies of ores and of animal and vegetable substances, of oil and coal. That would be—in other words—an outline of Economic Geography and the distribution of present and potential supplies of raw material about the earth. This would broaden out at last so as to amount to a résumé of the chemical composition of the entire globe, considered as a ball of raw material for economic exploitation.

§ 7. *Some Typical Modern Materials*

We will not attempt any complete inventory of useful materials here, but let us at least stroll about the human warehouse and see what is lying about in it and what invention and discovery have recently brought in and made available.

If it were possible to summon the whole *Science of Work and Wealth* into existence here, if we could thrust out our hands and eyes into the year 1940 and turn over the two or three hundred thousand pages that may then exist, we should find long, fascinating chapters devoted to the story of coal and oil, the story of iron and steel and of the metals and non-metallic minerals. There would be long descriptions, stage by stage, of mines and foundries, of the processes by which lead, tin, and other familiar metals are brought at last, tamed and submissive, to our hands. Modern discussions of the better utilization of coal would have produced their inevitable fruits. The already rich and eventful history of the distillation of coal, the story of gas and of the by-products of coal gas, would have had new chapters added to it. The oil chapter would tell of the refinery and of another great multitude of secondary materials arising out of oil. Here we can but intimate and sketch. We should read of copper refining—for the electrification of the world depends on copper; we should be told of the conquest of aluminium and of all that its lightness and strength make possible. On tin, they say, the food supplies of our urbanized world depend. But there the aluminium container and the "paper" carton may save the situation.

Had we limitless space the account of the distillation of coal would lead on to a description of aniline dyes, one only of the endless outcomes of that distillation and that would carry us on to an account of the dyes of former days, how rare and limited they were, and we should realize the great outbreak of colour in dress and furnishing and of scents and medical substances—as well as of frightful explosives—that the modern chemist has made possible. How did the colour of a ballet or a pantomime scene in the early nineteenth century compare with that of one to-day? I believe we should find it was extraordinarily flat and unsubtle.

Under the heading of non-metallic minerals we should read in that great collection of details we have imagined, an account, for instance, of the finding and trade in various precious and semi-precious stones and a little about diamond cutting and why it fixed its headquarters for so long at Amsterdam. No such discursiveness is possible here. And then there would come a survey of the material of the potter and the glass-maker and the comparative study of the ancient and modern cements. A brilliant array of modern pastes and enamels would follow. The vast architectural possibilities of reinforced concrete would be touched upon. But its fuller treatment would be better left for our chapter on the housing of mankind.

I seem to see before me a vast display of exhibits to comprehend longcloth, paper, celluloid, and a multitude of other such substances, brought together under the heading of "The Utilization of Cellulose," the substance of the ordinary vegetable cell wall. One branch of that utilization is the production of artificial silk. Hundreds of ingenious minds, crystallizing their results in thousands of patents, have led step by step to this one new item in the world's clothing.

The world's production of artificial silk in 1927 was more than 125,000 tons. A quarter of a century before, artificial silk was unknown. The story of artificial silk is a story of steadily accelerated invention. Réaumur, in 1734, suggested that artificial silk might be made from the solution of a gum. But the chemical knowledge of the time was insufficient to develop the suggestion. A hundred and twenty years later Andromars made cellulose nitrate by treating cellulose with nitric and sulphuric acids. This could be dissolved in a mixture of alcohol and ether, and when it was forced through a fine orifice, the alcohol and ether evaporated, leaving a filament of nitro-cellulose which could be converted into cellulose again without appreciable loss of form. That thread was the clue to the practical achievement of an artificial silk fibre.

For a time the technical difficulties of manufacture remained insuperable; Andromars' artificial silk fibre was a scientific curiosity and nothing more, and then a Frenchman, Chardonnet, worked out a commercial process. His attention was drawn to the matter while a student under Pasteur, when the latter was pursuing his famous investigations into silkworm disease. For thirty years Chardonnet struggled with his problem and at last worried through to success. He took out his first patent in 1884. His process is still in use, though the cost of the alcohol and ether was at first a serious disadvantage. Effective methods of recovering these had to be discovered.

A parallel process in which cellulose was dissolved in an ammoniacal solution of cupric hydro-oxide was worked out in France in 1900.

In 1902 Cross and Bevan discovered viscose, or zanthate of cellulose, a new and better material for the fibre, and from that time things went swiftly. By 1927 viscose formed 84 per cent of the world's artificial silk output. Three years later the same chemist invented the acetate process by which celanese is produced. All varieties of artificial silk are now known as *rayon*.

The raw materials used are cotton linters—the short fibres produced when cotton is "ginned" to remove the seeds; or wood pulp, obtained from spruce—usually *Picea excelsa;* and an abundant supply of pure soft water. From these materials not only rayon but also artificial horsehair, wool, narrow ribbon exquisitely delicate and fragile, films, sheets, and plastic masses of cellulose or cellulose acetate are now obtained.

When treated with camphor, cellulose forms celluloid, the material of camera and cinema films, of trinkets, toilet requisites, and toys, of collars, of cutlery, brush, umbrella and walking-stick handles, and of a thousand and one things, formerly made in bone, ivory, glass, china, leather, cotton, linen, wood, or metal. A sheet enclosed between two sheets of glass forms the unbreakable material used for the wind screens of motor cars.

Compounds of cellulose and acetic acid (the acid of vinegar) are used as "dope" for aeroplanes. They form a durable, glossy, and extremely tenacious film over wood, metal or fabric, and are replacing other forms of paint and varnish on account of the more attractive finish. Thin sheets of this material are used for wrapping food, and a film deposited on wire gauze forms a substitute for glass. All this variety of substances has been won from wood pulp and cotton refuse in the last fifty years.

It would be an interesting special study to trace the progressive introduction of animal and vegetable substances to industrial use. Leaving the ore heaps and chemical works behind us we should carry out our survey to the open, to the plantations and forests and wildernesses, where the "first state" of our substances is to be found. Some day we shall have precise estimates of the wild wastage of fine timbers that has gone on, and industrious students will have put in order the records of the modern search for fibres and paper, pulps and vegetable and animals oils. A history of materials if it is to be complete must also pursue the fur trapper and tell of fur farms and of the tragedy of sealing. How far is man killing off the whale and the ivory animals? There have been very hideous massacres of penguins for oil; it is a particularly moving story of waste and cruelty.

There is an interesting story behind this vehement search for animal and vegetable oils. Fifty years ago the chief demand for such oils came from the soap industry. Nobody thought of eating them or could have eaten them.

Soap is essentially a sodium or potassium salt of a fatty acid. The fatty acids are present in animals and plants in combination with glycerine. When these glycerides are treated with caustic soda or caustic potash the soda or potash displaces the glycerine, and soap is the product.

Tallow, obtained by boiling animal fat, was used for centuries for soap-making as well as for candles. Palm oil from Africa and olive oil from the Mediterranean region were employed for the choicer toilet soaps. And of these oils there was enough and to spare, until margarine became an article of manufacture. Margarine, however, is also made from animal oil, vegetable oil, or mixed oils. The principal raw materials are the oils of the cocoanut palm kernel, cotton seed, soya bean, or other plant products, and the fatty tissues of the caul and kidneys of cattle. These ingredients are mixed with skim milk which has been pasteurized and inoculated with lactic acid forming bacilli to make margarine. Most people over fifty can remember the introduction of this new synthetic and cheaper rival to butter and recall the prejudice it aroused.

Now the manufacturer of margarine soon outbid the soap-boiler for the better qualities of oils and fats. A scarcity arose, more particularly of the harder oils or fats. The difference between soft (fluent) oils and hard oils or fats is as a rule a difference in the amount of hydrogen they contain. The former have less hydrogen than the latter. It was the hard fats the margarine makers and the soap makers wanted and struggled to obtain.

The chemist in his laboratory, at that time, could produce a hard fat from an oil by the addition of hydrogen. But his processes were difficult to carry out on a commercial scale. The problem was solved finally by employing a general reaction discovered by Sebatier and Senderens. They passed hydrogen through the fat heated to a temperature of 140°C. to 200°C. in the presence of a finely divided metal such as nickel. Not only did this harden the oil, but it deodorized it. So suddenly not only were soft soils turned to hard, but whale and fish oils, which formerly had had a limited utility owing to their objectionable smell, were brought to the aid of the soap-boiler and butterman. The balance of supply was restored, and the quantity available was enormously extended. To-day whale oil can not only be used for soap, but also for margarine, salad oil, and other articles of food. So black olives lie wasting now in the olive orchards of Provence while native labour gathers the material for the world's salad oil in the East Indies and the African forests, and the whalers of the Southern seas supplement their efforts.

While the invention of margarine captured a great supply of hitherto unassimilable oils and fats for food purposes, the story of milk products shows us the reverse process of utilizing a periodically excessive supply of nutritive material for industrial processes. Milk has a constituent called casein. It is an albuminous substance similar to the white of egg. It is the curd which is precipitated when rennet or a dilute acid is added to milk, or when milk sours naturally. When dried it forms a white powder, and of this powder about ten thousand tons are now produced annually in the United States alone.

The buttermilk or skim milk from which it is obtained has a limited value as a food for domestic animals. But the white powder is used in confectionery and certain manufactured foods, in cosmetics and ointments, as an adhesive material for glass, china, paper, wood, and other substances, in printing and sizing cotton fabrics, for waterproofing paper, and for making distempers.

When the dried powder is compressed and then hardened by soaking in a solution of formaldehyde, it can be machined and polished. Alone or mixed with various filling materials or colouring matter, this moulded and indurated material imitates ivory, horn, bone, tortoise-shell, amber, ebony, and ornamental minerals like malachite. It is fashioned into toilet trinkets, inkstands, cigarette holders, the handles of cutlery, brushes, and umbrellas, and scores of other articles. The colouring and translucency of many of these things are exquisite. How many people realize that the manicure set and the morning milk have a common origin?

Another series of artificial substances of great modern importance are the synthetic resins. Natural resins are gummy liquids, which are exuded by trees, especially conifers. Amber is a fossil resin that has been valued since prehistoric times. But that is not the amber you will buy nowadays in the Rue de Rivoli. Resins differ from gums in being insoluble in water, and they are extensively used in varnishes. It has been found possible to make substances similar to natural resins by acting with formaldehyde on phenol and other products of coal tar or by subjecting these products to the action of heat, light, alkalis, or strong acids. Other synthetic mixtures are also made, to which coal tar does not contribute. Some of these false resins become harder and insoluble under the action of heat. The natural ones exhibit a contrary behaviour. These artificial products are used in varnishes and as insulating material for electrical apparatus. Since they will withstand a high temperature they have an advantage over rubber, ebonite, and celluloid. Bakelite, for example, which has become popular in a hundred varieties of bright-coloured ware, retains its form and properties when most other materials would soften or decompose. It is one of the most important insulating materials used in the electric industry. Another variety of resin is made from urea, or from thiourea, a by-product of the gas works, treated with formaldehyde. This can be tinted and is used for table and decorative ware of extraordinary delicacy and colour.

The American petroleum industry dates from 1859, when Colonel Drake drilled the first well at Oil Creek in Pennsylvania. Before that enterprise the American output (used as fuel) was only 2,000 barrels a year. To-day it is more than 900,000,000 barrels, or nearly 500,000 times greater and more than 70 per cent of the output of the world.

Petroleum is a complex mixture. By distillation at successive temperatures, the oil refiner obtains gases, naphtha, illuminating oils, lubricating heavy oils, and a residue of coke, pitch, or asphalt. Naphtha, on redistillation, is separated into petrol or gasoline commercial naphtha, and benzine, used in dry-cleaning. Similarly illuminating oils and lubricating oils yield different grades. each suitable by quality or price for a particular purpose. The heavier oils yield vaseline, petroleum jelly, and other now familiar substances. Paraffin wax, so largely used in the electrical industry—and for chewing gum!—is separated by cooling.

But the constituents do not exist in the proportions required by the modern world. The light oils have become more valuable than the heavy oils. So the heavy oils are subjected to the process of "cracking." A quick rise in the temperature of the still causes them to decompose with the formation of lighter oils. In this way the production of illuminating oils, and particularly of petrol or gasoline, has been greatly increased during the last twenty years. A natural balance has been adjusted to meet changing human needs.

And so building up that spectacle of the world's activities which is the object of this work, we must add to the scientific experimentalists and research institutions we have already evoked as the nucleus of the modern economic world, a multitudinous array of toil and enterprise. We must fling across our canvas an impression of mines and foundries scattered about and digging into the skin of the world, innumerable quarries of every sort of stone, oil fields with their gaunt cement works, brick fields, the production of clay and feldspar for potteries, coal mines, peat cutting, forestry, and lumbering, saw mills and paper mills and a spreading increasing variety of plantations for rubber, sericulture, cotton, flax, hemp, sisal, factories for cellulose products and all the widespread extraction and preparation of the stuffs out of which the appliances of civilized life, its tools, machines, houses, clothing and so forth are made. Here, except for our glance at margarine, we will say nothing of food. With food production we will deal later. That is the task of hundreds of millions of cultivators, the fundamental task of mankind, but here already we have millions at work of every race and colour, in every climate, winning and assembling the crude materials of modern industry in ever-increasing variety and abundance.

A special chapter of outstanding liveliness in that great Book of Modern Substances would give the history of plantation rubber—with the Congo, Putumayo, and the Stock Exchange in the picture. They are not in our picture as yet, for we have still a long way to go before we come either to the tragedy of defenceless peoples invaded and forced to labour by alien enterprise, or to the problems of overproduction and planless cultivation in our still essentially haphazard world. But here we may at least glance at the happier aspect of a new substance woven into our economic life. A hundred years ago rubber was as unimportant as electricity. The very name reminds us of its chief use, the rubbing out of pencil marks. (Have we not all of us in our infantile artistry suffered from the sulphur streak of the cheaper kinds?) Or the stuff served as the material of a bouncing ball. The Spaniards found the natives playing with solid rubber balls when first they reached South America.

The extensive utilization of rubber dates from 1839. Then it was found that heating rubber with sulphur (vulcanization) made it stronger and more elastic. With more sulphur still it became harder and even brittle. In my boyhood ebonite was used for trinkets, and the incorporation of paraffin wax and other petroleum products with rubber had begun. Ebonite toys were irritatingly brittle. Very fine rubber, containing oil, was in use for such things as the tubes and teats of feeding bottles. And it was in silk-elastic also and particularly in those dreadful and now happily vanished objects, spring-sided boots.

That was about all I can remember of rubber sixty years ago. It was still a mere accessory substance. It would hardly have been missed had it vanished altogether. Consider what has happened since then. Consider its use for electrical insulation alone. If by some miracle rubber suddenly ceased to exist, what would happen to our streets and homes? Silence and darkness. The telephone would cease to ring. Seven eighths of the wheeled traffic would stand immobilized in the streets. Within a lifetime rubber has passed from the status of a supplementary elastic substance to a position of fundamental importance.

At first it was a wild product, it was made from the latex of various forest trees and plants of which *Hevea brasiliensis* was the chief. It was collected, often under dreadful conditions, in Brazil and the Congo Free State. (We shall have a grim story to tell later about that.) In my childhood a few thousand tons of this ball rubber was all the rubber output in the world. Under the pressure of new demands, of which the bicycle tyre was the chief, the price rose, the hunt for wild rubber became more urgent and cruel, and the total product rose towards fifty thousand tons by the end of the century. Meanwhile the economic botanists of Kew were working out the problems of its cultivation. It was first successfully grown in Ceylon, and there followed a boom in rubber plantations; they multiplied in Malaya, the Dutch East Indies, Ceylon, Indo-China, India, Siam, and tropical Africa. The output of the cleaner and better plantation product has risen to over six hundred thousand tons, and prices have fallen until further production has become unprofitable. The quantity becomes the more impressive, and its bearing upon human work becomes plainer, when we remember that rubber is derived from a milky fluid which trickles at the rate of four or five pounds a year from cuts in the bark of trees, into small vessels hung beneath the cut. From that sticky treacle its drawn-out threads pass now to weave intimately and indispensably into the entire fabric of contemporary civilization.

All this, which we treat in a few brief crowded pages of evocation here, would unfold in a full and complete *Science of Work and Wealth* into a great mass of clear and well illustrated descriptions. This section is the intimation of a great volume. It would have to be a volume if once it began to expand. This material is the sort of thing that must be done either very fully or very compactly. There is no middle distance for a landscape of staple industries. Either you must see them from a remote distance, a reek of tall chimneys, clusters of strange sheds and retorts, tangles of conduits, gigantic dumps, a distant rumble of trains and machinery, or you must go right up to the blinding heat of the electric furnace and the intimate roar and beating of the machines. You must count the chimneys, weigh the fuel and assemble the records of output. At present we are doing no more than an aerial reconnaissance of all this side of human life.

As Crawford's admirable antiquarian work has shown, a man in an aeroplane can not only see more deeply into the sea than a man in a boat, but he can observe a multitude of land secrets, old ridges, ancient roads and enclosures, and differences in soil and texture that are altogether hidden from the man in the field. But the airman can see nothing of the daisies and knows nothing of the lurking life in the hedges and by-ways. Here we are, so to speak, aeroplane economists, more concerned with the past and the general hang of things than with particular instances.

§ 8. *The Story of Iron and Steel*

But though we have every desire to avoid overwhelming the reader (and the writer) by masses of detailed technicality, there is one chapter in the vast catalogue of modern substances which is so integral to our account of the modern world, tnat we cannot avoid treating it with some particularity. This is the development of the iron and steel industry which was vitally necessary to the conquest of mechanical power.

In 1700, iron was made in Britain with charcoal in small blast furnaces. Steel was got by heating pure wrought Swedish iron in contact with charcoal. This *blister steel*, so called because the process of manufacture resulted in the formation of blisters on the surface of the metal, was broken up, bound into faggots, reheated and beaten to *shear steel*. That was the only iron and the only steel in England, and there was not very much of either. How much, we do not know. In other countries matters were at as low or a lower level. Bars, fetters, railways, small cannon were the largest workings of iron; a sword-blade or a breast-plate was the maximum piece of steel.

In the early eighteenth century coke began to replace charcoal in the blast furnaces. Coke permitted heavier charges, heavier charges involved longer contact with the fuel, and a more fluid iron was produced. Coal-fired reverberatory furnaces appeared after the middle of the century, and puddling and rolling followed. Foundry and forge tended to concentrate on the coal fields, and industrial units grew larger. Shear steel gave way to cast steel for many purposes, on account of the relative cheapness of the latter, so soon as crucibles could be found capable of standing the high temperature necessary to melt steel. But shear steel (double shear steel) is still used- for high-grade carving knives, for example, and suchlike purposes. With this new abundance of steel, cutlery, fine-edge tools, steel springs became abundant in the world, facilitating scores of new processes and making hundreds of new conveniences possible.

By 1800 the world's output of iron and steel was perhaps over six hundred thousand tons.

By 1820 the production of pig iron in the world passed the million mark. Crawshay of Cyfarthfa could not turn out five hundred tons of bar iron in 1787; in 1812 he produced ten thousand tons. That was how things were going.

This flow of iron and steel into human resources made itself apparent in a number of useful things that had hitherto been impossible. In the latter half of the eighteenth century, not only was wrought iron being largely used, but cast iron was being extended to a number of purposes. The first iron bridge (cast iron) was constructed across the Severn in 1777–79 by Abraham Darby. An iron canal boat was built and launched by Wilkinson in 1787. Cast iron was used for tramway rails from 1767, and wrought iron on the Stockton and Darlington railway in 1825. Iron in quantity had solved that problem of the railway, which had entirely baffled Roman civilization.

In 1788 about half the pig iron produced in England was puddled. The steel was made almost wholly from imported iron, and employed only for cutlery, tools, and springs. The amount must have been relatively small. Nowhere in the world was steel used for anything but cutlery, tools, weapons and springs.

Cast iron, wrought iron, shear steel and cast steel were all available for human use in 1800. There were several grades in each. The quality depended upon the purity of the ore, whether the fuel was coke or charcoal, and upon the judgment of the workman. The purest ore was Swedish magnetite, but there were also inferior varieties of iron from Sweden. Some ores contain phosphorus, and iron containing this element is "cold-short," or brittle when cold. It was used for little but nail-making. Iron melted by coke was liable to contain sulphur. This caused "red-shortness," that is to say brittleness when red hot.

A sample of steel in those days was found to be suitable or unsuitable on trial. Even rough chemical analysis was hardly available as yet and quantitative chemistry had still to come. A sample was examined by breaking and noting the fracture. That is still used as a rough test to-day. But there were neither testing machines, nor quantitative methods of analysis, nor metallographical methods. No organized knowledge, in fact, but merely empiricism and experience.

Neilson's invention of the hot blast in 1829 introduced an economy in fuel and enabled the Scottish blackband ironstone to be smelted. The temperature of the blast was raised to 600° F. That was a great achievement for the time. To-day temperatures of about 1800° F. in the blast furnaces are not unusual. Wrought iron continued to be made by the laborious process of hand puddling for many years. In 1856-60 the Bessemer process of blowing air through molten pig iron to burn out impurities and then adding carbon and other ingredients to make steel came in, and for the first time steel became cheap and available in bulk. Castings of steel up to 25 tons became possible. The open hearth appeared in 1864, a gas-fired furnace in which pig iron and scrap iron are melted in an oxidizing atmosphere. Steel castings of over one hundred tons became possible, and the quantity of metal produced increased and increased. From one American open hearth two hundred tons of metal have been pouring every three or four hours since 1927. We have several hundreds of tons of steel to-day for every ton of iron or steel the world could produce in 1800.

Each advance in the size of iron and steel castings opened up new possibilities of handling and utilization. Lifting appliances for heavy weights, for example, could only exist when metal was available in huge castings. Otherwise you could not make a sufficiently big crane. In 1800 not mere than a ton or so could be lifted. To-day 5-, 10-, and 20-ton cranes are common and castings of 50 or even 100 tons may have to be moved. Generally any casting of more than 100 tons is made in two or more parts to be bolted together. But a 50-ton mass can be handled with more ease to-day than a single ton lump in 1800.

In America 11 per cent of the steel produced is used in the form of pipes. The production of pipes was a very difficult process in 1800, and little if any iron pipe was made. There are two methods of pipe-making to-day: either a flat sheet is rolled and the edges are welded in a longitudinal joint, or the metal is rolled over a pier to form a cavity and a seamless tube is produced. Seamless iron pipes are also made by means of centrifugal casting. The high pressures now being tested in power stations (600 pounds to 1,200 pounds per square inch) would be impossible without seamless tube. So one thing leads to another, and impossibility after impossibility crumbles away before the advance in substance control.

The electric furnace came into use in 1890. It is largely employed in the manufacture of the alloy steels used in motor-car construction, and for the stainless steels. Since it asks for water power rather than coal, it has been extensively developed for tonnage steels in Italy, where there are 200 furnaces in operation. The high frequency electric crucible furnace has been introduced since 1927. With this, the highest classes of tool steel can be produced. It contrasts very vividly with the crucible furnaces it is replacing. Formerly you had men standing astride white-hot coke furnaces, enduring the most terrific temperatures as they lifted out the pots of steel by their sheer unaided strength. Now, at the pressing of a button, eight times the quantity of metal is poured out, in a fourth of the time.

The world output of pig iron in 1927 was 85,270,000 tons, and there had been an increase in every decade since 1800. The production of steel in the same year 1927 was 100,180,000 tons. This disproportion is due to the fact that large amounts of steel scrap and iron ore are used in steel making and that a considerable amount of steel contains elements other than iron and carbon. The figures are not comparable. Steel has largely replaced wrought iron for all constructional work and for parts of machinery where strength, resistance to shock, and durability are required. We may compare the 85,270,000 tons of pig iron with the annual output of 650,000 tons in 1800. It is 131 times as great. But the increase in the quantity of steel would be even more striking if the figures were available. To-day we have hundreds of tons of steel for every ton of either wrought iron or steel available in 1800.

And meanwhile steel, which was a distinctly mysterious iron product in 1800, has had its composition studied, analyzed and controlled.

In 1800 steel was just the substance of a knife blade or a sword. It was one substance, so far as was known. But now we have on our economic bill of fare not one steel but dozens. There are first the carbon steels. These contain iron and carbon with only traces of other elements: phosphorus, sulphur, silicon, manganese. All tonnage steel (steels made in large quantities) contain 0.3 per cent and upward of manganese. There are seven grades of carbon steel known as: extra soft, structural or mild, medium, medium hard, hard, spring, and carbon turning-tool quality. It is the first two grades which have so largely replaced wrought iron. The softest cannot be hardened. It can be case-hardened. (Case-hardening consists of heating the metal in contact with carbonaceous material whereby carbon is absorbed, giving a surface of harder steel.) It is workable either hot or cold, and is used for thin sheets, which are cold-rolled, rivets, which have to be beaten out, pipes which have to be bent, and smith's bar.

Structural steel is used for bridges, boilers, and railway rolling stock. Medium steel is used for shipbuilding and machinery. Medium hard for large forgings, parts of locomotives, car axles, rails. Hard steel for wheels, tyres, wood-cutting tools, etc.

All these carbon steels can be forged and machined, but with increasing difficulty as the carbon content rises. From medium steel onwards the quality depends largely on the heat treatment to which they have been subjected. Hardness is increased at the expense of ductility, and is often accompanied by brittleness.

The following table from the Encyclopædia Britannica indicates the kind of variation:

Material	*Ultimate strength*
Rivet steel	50,000 lbs. per sq. in.
Medium hard	75,000 .. ..
Spring after quenching	200,000 .. ..
Spring steel	150,000 .. ..

These seven grades have a total extreme difference of carbon content of only 1.2 per cent (from 0.08 per cent to 1.2 per cent). They illustrate the extraordinary effect of minute quantities of this element on iron, and they show the remarkable accuracy with which metallurgical operations are now conducted. A hundred tons or more of metal may be poured into a mould and not differ from the required proportion of carbon by more than 0.1 per cent. Other elements, particularly manganese, nickel, chromium, tungsten, molybdenum, cobalt, and vanadium, when present in certain proportions, have a powerful influence on the qualities of steel. Manganese in quantities below 1.0 per cent strengthens and toughens iron. Very strong castings are made with 1 per cent to 2 per cent manganese.

Silicon steel, or to be more precise silico-tungsten steel, is used for long-span bridges, boilers and in shipbuilding. It has a strength greater by 10,000 pounds per square inch than older kinds used for boilers. Its ultimate strength is 120,000 pounds per square inch, and a test piece stretches 23 per cent before breaking. A 0.9 per cent carbon steel with 1.65 per cent manganese, undergoes very small distortion during heat treatment (hardening and tempering) and is used for dies and gauges. Hadfield's manganese steel has 11 per cent to 12 per cent manganese, and 1.0 per cent to 1.2 per cent carbon and was for long the toughest material known, though it has now given pride of place to the austenitic nickel chrome steels. It resists shock and wear, and is used for tramway points, dredger buckets, crusher jaws, and the like purposes.

A carbon steel tool has a relatively low limit of cutting speed. If the speed is too high it becomes hot, loses its temper and its edge. Higher speeds were found to be possible with the tungsten-manganese alloy invented by R. Mushet between 1860 and 1870. This was self-hardening by heating to a high temperature and cooling slowly. Similar steels containing tungsten and chromium were used in America. It was supposed that the temperature of hardening should not exceed 815° C. to 845° C. But Taylor and White (Bethlehem Steel Co., Pa., U.S.A.) after twenty-six years' research discovered in 1900 that if heated to 1040° C. to 1100° C. its hardness was greatly increased, and the tool would cut at a red heat without loss of edge. This was the first of a number of high-speed tool steels. No need to cool off; no need to slow down: they drive on. In some cases cobalt is added to these steels, and it will be news to many readers that there are now several high-speed tool "steels" which do not contain iron. Stellite for example has cobalt 55 per cent, tungsten 15 to 25 per cent, chromium 15 to 25 per cent, and molybdenum 5 per cent. More recent and more important now than stellite is tungsten carbide.

The practical consequence of man's conquest of these new materials may be gauged by the fact that, with a particular quality of steel in the lathe and the same depth of cut, a plain carbon steel cuts at 16 feet per minute, an air-hardening steel cuts at 26 feet per minute, or, after quenching, 60 feet per minute, and a modern high-speed steel 100 feet per minute or more. With softer material and lighter cuts a speed of 150 to 175 feet per minute is attained. Under favourable conditions tungsten carbide will remove the metal at over 300 feet a minute. The writer has seen it cutting cast iron at as high a rate as 400 feet a minute.

I will not dilate here upon nickel, chromium, and nickel-chromium steels. The effect of each element is to toughen steel and to enable hardness to be secured without brittleness. They are more effective in this when used together. Stainless steel has more than 10 per cent (often 13 per cent) of chromium. Nickel steels are used in bridge and structural work generally and for boilers. They are heat-treated for guns, engine forgings, and shafts. Chromium steels are used for projectiles, grinding rolls, and roller bearings, and with nickel or vanadium for armour plate, or, heat-treated, for axles, machine parts, and gearing.

At one time aeroplane and automobile were entirely dependent on tungsten steel, because it was the only steel possible for the permanent magnets in the magneto until chrome steel (for cheaper types) or cobalt steel became available. Tungsten can be produced in a ductile form and is then used for the filaments of electric lamps. It has entirely superseded the earlier carbon filament, and it made wireless telephony and broadcasting possible. The earlier forms of thermionic valve essential to a receiving set could not have existed without tungsten. . . .

But enough of such facts have been given for our present purpose. We must draw back before the serried facts overwhelm us. The little steel sword blade of our great-grandfathers has become the framework of bridge, railroad, ocean liner, sky-scraper, and ten thousand other things. In a locomotive or motor car to-day you will find a score of different steels, all beautifully adapted to the work. I will not attempt to estimate the hundreds of thousands of patents, the scores of thousands of inventive minds, that have gone to the making of this one chapter in the multitudinous history of substances. I have left the tale abbreviated, cut down, and only half told, and side by side with it could be set a score of parallel tales.

An adequate Book of Substances alone would make a stupendous volume. You would never read it; you would only read in it. You would insist upon a comprehensive index and go to it ever and again for a fact. Here you have been given all and more than you need. One adviser has already remarked that some of the pages immediately preceding this read like "extracts from an article in the 'annual review' of a technical journal"—and how else could they read? And such a Book of Substances would give only the material basis of the spectacle of human activities, the material basis only of the life of work, wealth, and enjoyment we are setting ourselves to survey. It would be only an introduction to the more crowded books that would follow it. Happily our main argument is possible without the actual production of that interminable catalogue.

§ 9. *The Conquest of Power. Sources of Power*

And now we come to a group of facts so important to the modern world that, as I have told in the Introduction, I thought of calling this entire work by its name, the *Conquest of Power*. There is also a reverse title to that: the *Abolition of Toil*. Yet it is not merely that mechanical power has replaced toil over a vast proportion of the field of human effort. That is only a part of what has happened. There has been an enormous *addition*, an altogether disproportionate extension of the energy available for human ends.

We have distinguished in man's history a prehistoric, casual-living, sub-human stage; a stage in which social life and tradition appear and human life is retrospective and ruled by precedent and historical legend; and this present third stage in which we are living, with science and design rapidly ousting tradition from its domination over human life.

The age of tradition was also the age of toil. The traditional social life is and always has been pyramidal, with a mass of toiling workers as its base. This modern life that opens before us seems likely to have an entirely different structural scheme.

Toil, like tradition, is a distinctively human thing, made possible by the intricate reactions of the human cerebral cortex. Toil is sustained work done against the grain and giving no essential satisfaction in itself, done because the individual indisposition for it is overcome by some more powerful system of motives. A few of the more intelligent gregarious animals have also been made to toil by human compulsion, horses, oxen, and the like, but outside the list of these exceptions there seems to be no real toil in animal life. Most living creatures will not stand toil. They will resist to the death. The "workers" of the ants and bees are not toilers: they work by instinct; it is what their structure dictates and what they want to do. The scarabæus, rolling its dung balls, is no more toiling than the nightingale singing in a tree.

But human "*toil*" is not instinctive, not as people say a "*natural*" thing. Work may be a natural thing. Much human work, the work of a sincere artist, writer or inventor, for example—expressive work, as we call it—is not toil in the sense in which we are now using the word. It does not go against the grain. But the spectacle of human history shows us a long succession of generations in which a great majority of the community was *subdued to labour*. The muscular force of this labour class, doggedly applied, was the main source of power, the driving force of the social mechanism. The community could not have gone on without that subjugation.

In a brief century or so science and invention have rendered the bulk of this muscular exertion superfluous. It is no longer necessary that man should virtually enslave his fellow man; he has found new slaves, gigantic slaves, out of all proportion mightier than the human hands and muscles that hitherto have thrust and moulded obdurate matter to human ends.

A complete history of the Conquest of Power[*] would open with a brief review of the sources of power in the early civilizations. It is a meagre list of accessories. Except for the department of transport, wherein wind and stream and pack animal played important parts, for a certain limited use of wind wheels and water power as well as beast power for grinding and irrigation it was human muscle that kept things going. Even on the sea the galley was preferred to the sailing ship.

From this review of the ancestral equipment the record would pass on to the pryings and guessings of more ingenious spirits of the Middle Ages. At the time such enquiries must have seemed the oddest, obscurest, least important of activities.

Each machine was a curiosity because it was unique. It was designed for a particular purpose. This purpose loomed so large that it obscured the general principle. Whatever the motive power —wind, water, horses, or bullocks might be used—it was part of the machine. The first idea of a Prime Mover, capable of driving a

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[*] *The Quest of Power*, by H. P. and M. W. Vowles (1931), gives the story from windmill and water wheel onward, very interestingly and in ampler detail than was desirable here.

variety of machines, appears in the work of Leonardo da Vinci.

The sixteenth and seventeenth centuries produced a number of pioneers whose work, like so much pioneer work, was more notable for its failure than for its success. But as children say in the game of "hide and seek," they were getting hotter and hotter. Then, suddenly, like a new and splendid theme taking possession of a musical composition, deliberate invention and discovery break into human history.

That fuller story of the Conquest of Power we are imagining would note the early attempts to use steam, and it would "feature" James Watt very prominently at the opening of the new phase. It would trace the increasing efficiency of steam generating. It would give pictures and descriptions of the older and most modern types of steam engine. The steam turbine has opened a new modern chapter in the history of steam. From the turbine the Power Book in the *Science of Work and Wealth* would pass to a second type of power production, the internal combustion engine, in which the intervention of steam is dispensed with and the explosive combustion of a jet of gas or a spray of finely divided liquid is applied directly to give the thrust of the engine.

How rapid this development has been may be illustrated by a few facts. The "Otto" gas engine of 1876 was the result of 100 years of effort, largely fruitless, except for the temporary success of the Lenoir engine six years earlier. The fuel was town gas—far too expensive for large-scale use. Dowson in 1878 exhibited a gas producer in which cheap coal slack was employed, and Sir Frederick Bramwell prophesied that within fifty years the gas engine would replace the steam engine as a source of power. He was wrong. He under-estimated the world's capacity for power. He did not foresee the variety of purposes to which power would be applied. It was not clear at the time that steam engines of ten, twenty, and to-day of over fifty thousand horse-power would be built.

At that time the oil engine had not appeared. Daimler invented his petrol engine in 1884, the year that saw the first steam turbine. Parsons' first patent for a reaction turbine was followed a year later by De Laval's patent for an impulse turbine. Priestman invented the first medium oil engine in 1885, and in 1892 Diesel patented the heavy oil engine with which his name is now inseparably connected. The first Diesel was built in 1895, but it took twenty years to work out the subsidiary problems of this type. These three stages in the evolution of the oil engine used successively cheaper forms of fuel, while the actual consumption of fuel in medium and heavy oil engines per brake horse-power has been reduced since 1890 by more than one half. In the last few years the oil engine has been ousting the steam engine in a hundred different fields.

The heavy oil engine competes now with the steam engine in driving factories, in pumping, in the production of electricity, in the propulsion of ships, and is even threatening the steam locomotive. How great the success has been for ship propulsion is indicated by the fact that in 1930 the world's output of new steamships was 148,176 tons, and of motor ships 1,468,235 tons. The Italian motor-ship *Augustus*, built in 1927, is 32,650 tons burden.

The light oil engine made the motor car and the aeroplane possible. Since 1915 the weight per horse-power of an air-cooled engine has been reduced from 3 lbs. to 1½ lbs. The accuracy of workmanship and delicacy of adjustment of these high-speed engines are among the great mechanical triumphs of the age. They run at from 1,000 to 4,000 revolutions a minute. For the sake of simplicity suppose the speed is 1,200. Then there is a revolution every twentieth of a second. In half that time, in one-fortieth of a second, the engine makes a stroke. At each stroke the valves open and air and fuel are admitted, or the mixture is compressed, or it is exploded, or the valves open and the spent gases are swept out. The spark which fires the mixture must take place at exactly the right moment. It must be adjusted to an almost infinitesimal fraction of a second. The inlet valves open and close with marvellous precision. The exhaust valves act in turn, though they are at a bright red heat. High temperatures, high pressure and high speed are here brought into co-operation in a way which would have amazed the engineers of an earlier generation.

Let us explain here a few of the more important developments in the utilization of fuel.

The special advantage of a *gas* is that it can be intimately mixed with the proper amount of air for complete combustion. Only a slight excess is required. A *liquid* fuel possesses a similar advantage. The lighter oils are vaporized before burning, and the heavier varieties are broken up into a spray by a jet of compressed air. Liquid fuels have the special merit that they are easily stored and so can be transported economically over longer distances. The burning of a *solid* fuel is by comparison slow and irregular and from 120 to 150 per cent more air than is required for combustion has to pass through the furnace and flues. The use of mechanical stokers and continuous agitation of the fuel may facilitate the removal of ash and increase the rapidity and regularity, but they hardly affect the excess of air which lowers the furnace temperature.

The distillation of coal in retorts yields gas, ammoniacal liquor, tar and coke. This process has been in use for the public supply of gas for over a century. A modification of the process in which the yield of gas and liquid products is of secondary importance is employed in the preparation of the hard, dense coke for metallurgical furnaces. Coke-oven gas is now used to supplement the gas-works product for public supply. But coal (usually breeze or slack) and coke can be converted wholly into gas (producer gas or water gas) by blowing air, or air and steam, through the hot material. Gas obtained by the distillation of raw coal contains mainly hydrogen (about 40 per cent), methane (21 to 28 per cent), and carbon monoxide (8 to 15 per cent). The new low temperature carbonization process gives percentages of 29, 49 and 8 respectively. From 5 to 8 per cent of nitrogen is present also. Producer gas is carbon monoxide, and water gas is carbon monoxide and hydrogen. Both these gases contain a large percentage of nitrogen, which serves merely to dilute the mixture.

Coal contains excess of carbon which can only be converted into combustible gas by burning in a regulated supply of air. It is this air which brings in the diluent nitrogen. Attempts have been made to convert coal, with the exception of the small percentage of ash, wholly or almost wholly into combustible liquids and gases, mainly in order to increase the supply of liquid fuel, but this work is still in the experimental stage. The competition of gas and petroleum has, however, led to another way of using coal—particularly the breeze or slack, which is too small for many industrial purposes. The material is ground into a fine powder, dried and fed into the furnace through a nozzle by the aid of compressed air. Combustion then takes place, as in the case of a gaseous or liquid fuel, and only 20 to 30 per cent excess of air is required. There were tentative experiments on this method forty years ago, but the main progress has been made in the last ten years. The annual consumption of pulverized fuels is now about 150 million tons. It is used for firing cement kilns, in metallurgical furnaces, and for steam-raising.

All these ways of using fuel aim at economy but do not necessarily involve a reduction in consumption. The tendency is for power spread ever more widely over the world to exploit new or old sources of raw material and to provide increased facilities for transportation and other public services. The capacity to employ power seems to be illimitable. And yet fuel, solid, liquid or gaseous, is not inexhaustible. Oil can never satisfy more than a fifth of the world's present dependence upon coal. And the coal "in sight" will last, at the present rate of consumption, for twenty generations or so. Twenty generations back in our own history takes us to the Hundred Years' War, the Black Death, the First Statute of Labourers, the Peasants' Revolt, and the First Navigation Act. The changes since then have been many and, in a sense, revolutionary. But the changes in the next period, especially as they affect human life and work, will appear more numerous and still more revolutionary to those who will look backwards as we do to-day, but over twice the length of time.

As it nears exhaustion, coal may become more valuable as a source of raw material for the chemical industry than as a means of obtaining mechanical power.

Here, were we aiming at encyclopædic completeness, would be the place for a survey of the automobile and aircraft engines of to-day. In that encyclopædic expansion there would have to be a great mass of information about modern engines and a vast multitude of figures and diagrams. Such details would be interesting to those with a special aptitude for these things; for most readers they would stand unread as reassuring and confirmatory matter, and they would add nothing to our general exposition.

But a point we have to note here is the extreme transitoriness of this phase in mechanical evolution, in which power is derived from the combustion of natural substances like coal and oil. The employment of steam was the means by which man broke through to the idea of power machinery; and it was only with great advances in metallurgical science that the explosive engine became possible. But these advances have now been made and man turns again to the wind wheel and to water power, to the force of gravitating water, of which indeed since the very beginnings of his economic life he had made a dribbling little use, for water-lifting and the like, but which he could never use properly before our present phase of metallurgical attainment because of the inadequacy of his water wheels and his lack of transmission contrivances. Dr. Herbert Levenstein* speaks of the coal-power and oil-power age, "the age of fossil power," as a mere incident in the economic evolution of mankind. "It will have lasted, when it is over, for a shorter period than the Moorish occupation of Spain."

Now, with the electric current discovered and at his disposal, man has no difficulty in transferring the force of the windmill or water wheel to the most distant points of application, and the advance of metallurgy has converted the flapping wooden wheel of the old-world miller into a mighty interceptor of the rush and weight of stream and waterfall. The economic world turns back from fuel to this ancient and hitherto scarcely exploited resource of water power. So long as the world spins and the sun shines and the rain falls, there will be no end to the perpetual renewal of water power. It is the widow's cruse of economic life. So long as the wind blows, the wind wheel also will gather momentum. It is possible that in the near future the use of fuel will be confined to such freely moving mechanisms as ships, cars, and aeroplanes, or to the generation of power *in situ*. From the factory or from the fixed transport line, fuel-driven engines may disappear altogether.

The revival of water power is extraordinarily recent. It waited on the electric lamp, which came about 1880, and on the combination of engineering and electrical knowledge in electric generator design which was only achieved completely within the next decade. It was about 1890 that big hydro-electric power plants began to appear, and they were stimulated in some cases by the discovery of electrical processes of manufacture. Aluminium, carborundum, calcium carbide, graphite, and a host of other things were more economically produced, or could only be produced, by electrical energy. In Ontario and Quebec, where there is no coal, the hydro-electric plants are producing power that would require 30,000,000 tons of coal a year. What would the extent of the manufacture and the facilities for transport in that million square miles of country be like if they were dependent upon coal?

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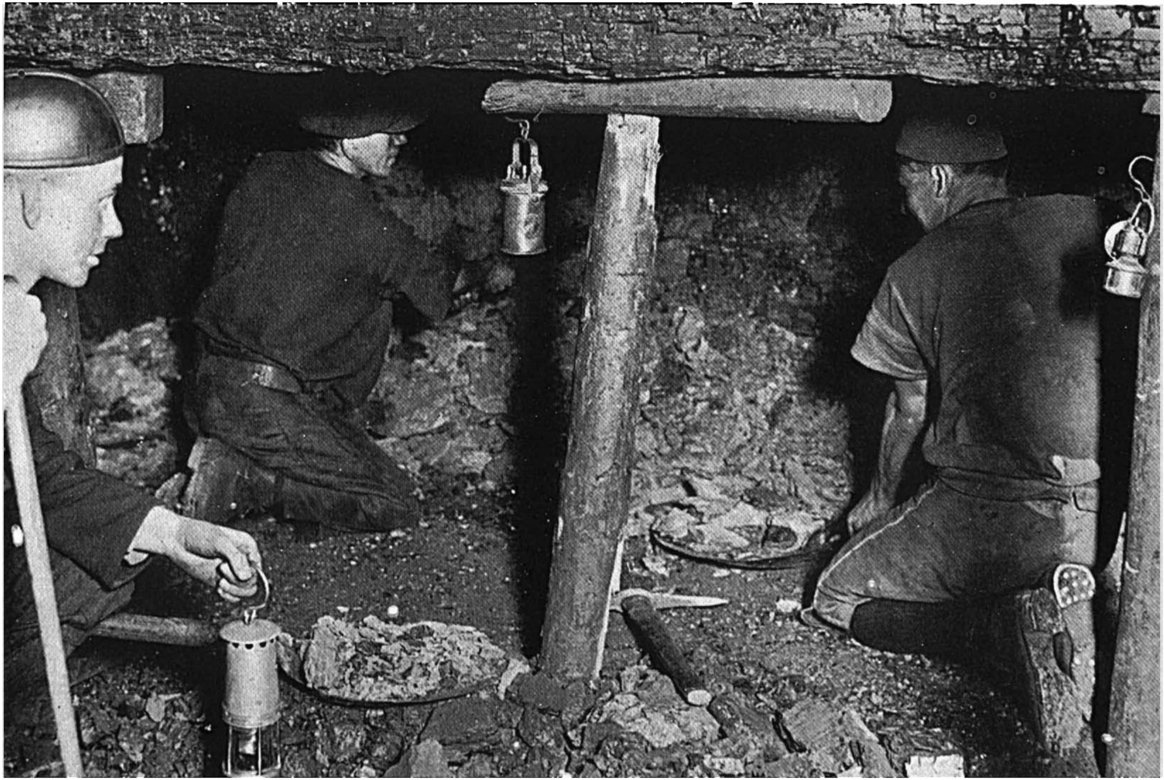
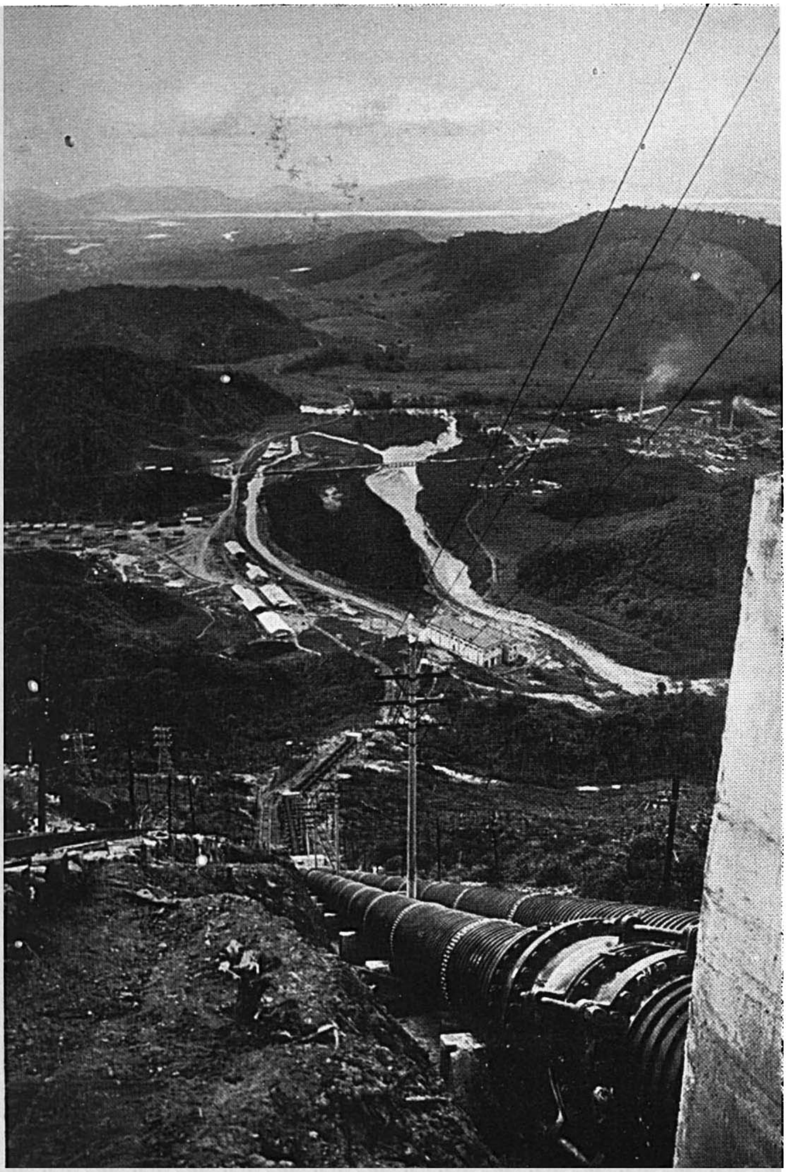
* Address entitled "But an Apprentice in Nature's Workshop," Soc. of Chem Indus., July 15, 1930.



(By courtesy of Allied Newspapers.)

OIL HAS NOT YET OUSTED COAL

Miners at Seghill Colliery, Northumberland



(By courtesy of Messrs. Perrins, Ltd.)

THE TAMING OF THE WATERS: SERRA, BRAZIL

The flow of the rivers has been reversed by raising their levels and storing their waters by means of dams, and then plunging them over a precipitous drop of more than 2,000 ft. in height

In Canada, water provides 600 horse-power per thousand of the population; in Switzerland, 500; in Norway, more than 700; in Sweden, more than 200; in the United States, more than 190. In Great Britain, the source of power remains the coal supply, and water power accounts for only a very small fraction of a horse-power per thousand people.

Here perhaps we may make a remark in anticipation of the chapter we shall devote to the housing of mankind. People have seen in the easy distribution of power a possibility of scattering population more evenly over the countryside. But in spite of the ease with which electricity can now be distributed over long distances, there is little sign at present that this is going on. Electrical power distribution is tending rather to form concentrations at new centres either near the source of power or where it is convenient for inter-related industries to use one another's products or by-products. The population map changes, of course, as the methods of utilizing power change, but so far no dissolution of the great town is occurring.

Are there still any undeveloped possibilities of extracting power from the movements of air or water? An exhaustive Power Book would summarize the present phase of the still unsolved problem of using tidal force. And further it would have to note and describe one or two odd and as yet impracticable contrivances for the direct capture of radiant solar energy. In the Kaiser Wilhelm Institute at Dalhem, Dr. Lange has run a small electric motor by sunlight, passing the light through a photo-electric cell. This little motor of Dr. Lange's may figure in the economic histories of the future as Hero's steam engine figures in those of to-day.

Many suggestions have been made for utilizing the internal heat of the earth by means of deep bore holes in the crust. In an indirect way this source is already being tapped. From steam which issues from the earth at Ladarello, in Tuscany, Prince Conti obtains over four thousand horse-power, and there is a similar scheme under development in California.

A high temperature is not necessary to produce power. A vapour engine, like the steam engine, requires water at a temperature which will produce vapour, and water at a lower temperature which will condense it. The difference between the energy of the vapour at higher temperature and its energy at the lower temperature, is the energy available for external work. Such a difference of temperature exists in nature between the warm surface waters of the ocean, especially in the tropics, and the cold water which flows along the ocean floor from the poles. After preliminary experiments in Belgium, Dr. Georges Claude is constructing a large-scale engine based upon this principle on the coast of Cuba. At Malanzas Bay bottom water can be pumped from the depth of a mile and a half through a 13-foot pipe and used to condense the steam given off in a low-pressure chamber by the hot surface water. There is a difference of 14° C. between the cold and hot water, and this, it is alleged, will suffice to run a practicable and paying plant. Here we may have another way of utilizing the heat of the sun on a larger scale than those devices of mirrors, lenses, and so forth, which attempt to employ the concentrated rays to produce a high temperature.

We mention these various notions here for the theoretical interest rather than for any immediate practical value they possess. They help one to grasp the idea of man's return from combustion as his source of power to the spin of the earth, the tides and currents of the seas, differences of velocity, pressure and temperature in the incessant stir of the world machine. All combustion sources are vanishing sources. In the end the rotating planet must become man's sole dynamo, the Prime Mover for all his mechanisms.

§ 10. *Transmission of Power*

Having got his power, man's next problem is the application of it to the task to be done. The power has to work this or that apparatus or drive an implement in contact with material undergoing manufacture; it has to be transmitted to the point where that is done. First our encyclopædia would discuss rope, chain and belt drives in the factory, with the problems of friction that arise, and then come to the use of compressed air and impelled water as power transmitters.

The transmission of power by toothed gearing is very ancient. The "teeth" were wooden pegs driven into the rim of a wheel. From the fifteenth century to the nineteenth actual cogwheels were made of cast iron, brass, or bronze. In the latter half of the nineteenth century they began to be made of steel. But in spite of the teeth being cut as nearly as machinery would allow to the exact geometrical shape, so that they would "roll" upon each other, there were still inequalities which produced noise.

One of the difficulties of applying the steam turbine to ship propulsion was the high speed of the turbine and the relatively low speed at which the screw propeller is efficient. The toothed gearing then available was far too noisy. The noise arose from errors in the machine in which the teeth were cut, and which were unavoidable. Sir Charles Parsons showed how to distribute these errors all round the wheel and succeeded in producing gearing which is very nearly silent, and in which less than 2 per cent of the power is wasted in friction.

Again belts and ropes passing over pulleys have been used for many centuries. They extend the range of transmission from a few feet to a few yards. The range is further extended to a mile or more by the use of high-pressure water. Though electric lifts are becoming more common, there are still many hydraulic lifts in docks, harbours, factories, warehouses and hotels and blocks of offices in large towns. How many people realize that the latter depend upon a public supply of water at high pressure laid under the streets like the ordinary water mains?

During the last twenty years some beautiful hydraulic transmission devices, using water or oil, have been invented. They are used to transmit power to machinery and to control the power transmitted according to requirements.

Compressed air has long been used, though it is not very economical since heat is evolved on compression. Nevertheless, air is found to be convenient for many purposes. The South African mines use nothing but compressed air.

During the war a Roumanian--M. Constantinesco—devised a method of transmitting power through water by waves. The water was contained in a long, closed, flexible pipe, and the waves produced by a series of taps on one end. These are reproduced with little loss of energy at the other. It was used first to "time" the discharge of a machine gun on an aeroplane so that the bullets would pass *between* the blades of the propeller. It has since been applied to rock drills.

The hydraulic and wave transmission devices, together with many forms of flexible coupling of the last twenty years, are ingenious additions to methods which sufficed for many centuries. They are novel in principle or design, and they indicate that neither mechanical ingenuity nor the application of scientific principles is exhausted in this field.

The next subject in order would be the electric generating station and electrical distribution. Our encyclopædia of reference would have to explain how the powerful rotation we have won from steam or water is made a source of electric current. It would expatiate upon the working of a dynamo and give pictures of dynamos and power stations. Then the description would proceed to spread out for us our living wires and cables, marching across country, burrowing underground, carrying power to farm and factory, home and road.

Electric energy was not produced on a very large scale until the late eighties of last century, nor was it transmitted very long distances. To-day, two or three hundred thousand horse-power is utilized more than two hundred miles from the source. The voltage, or pressure, at which the electricity is conveyed has risen in forty years from 10,000 to 220,000 volts. For testing the equipment of such a line, apparatus yielding electricity at 1,000,000 volts is employed, and a flash of artificial lightning 17 feet long is produced by its discharge.

Wonderful it is to reflect that a hundred years ago the very idea of a power station distributing driving force to road, car and factory, lighting and heating cities, and so forth, would have been incredible, and that even the "power house" with its rackety steam engine, driving the machinery in a factory by band transmission, is not a hundred and fifty years old.

§ 11. *Points of Application*

Consider now the various points of application of this power we can distribute so widely. The domestic and agricultural ends it serves are very diverse. But for most industrial purposes the point of application is the tool. In § 8 of this present chapter, we have described how the development of steel alloys has permitted a more and more rapid use of tools. We have noted already in our historical introduction, how improvement in one field waits on improvement in another. Here in the correlation of metallurgical exactitude and tool precision we have a modern instance. Our story of the machine tool is a history of ever-increasing speed and precision.

In the eighteenth century the art of working in metals was in a very primitive state. The cylinders of some of the early engines were of wooden staves, held together with iron bands, like a barrel. Before Watt entered into partnership with Boulton, he complained bitterly of the lack of skill displayed by mechanics. Some of his cylinders differed from circular section by a quarter of an inch! The machines used for boring them were that much clumsy and inaccurate.

Maudslay, towards the end of the eighteenth century, improved the lathe. But the most important step towards precision was taken by Whitworth. He introduced standard screw threads and made a machine that would measure to a millionth of an inch. The test piece could not be touched with the finger if an accurate measurement was required. The warmth of the hand caused it to expand by an amount which was measurable by the machine. Sellers rendered similar service by standardizing screw threads in America.

The next stage towards accuracy was the introduction of gauges. Rule and callipers were not sufficiently delicate, so the work was tested by standard rings, plugs or notched pieces of metal. Then limit gauges came into use. It is easier to machine a piece of metal *between* two dimensions than to an exact dimension. So gauges were made in pairs, and the work was made larger than one and smaller than the other. Work is now accurate to within a thousandth or a two-thousandth of an inch.

Parts of machines made in this way are interchangeable. It was no longer necessary to make a single machine. Parts could be made in dozens, hundreds or thousands, and stored. Any set of parts, selected at random, could then be assembled, and they would fit as perfectly as if they had been made individually for the purpose. Mass production became possible. Sewing-machines, typewriters, cash registers, bicycles, and a host of things became plentiful and, with the advent of automatic and semi-automatic machinery, relatively cheap. The process was extended upwards to heavier machinery. To-day a motor-car and a 250 horse-power Diesel engine are assembled in the same way as a cash register.

Before passing to the stores, the parts are inspected to ensure that they are within the prescribed limits. In some cases an optical test is used. The part is projected in profile upon an enlarged drawing on a screen, and any slight departure from accuracy is revealed. The drawing is usually made with double lines representing the limits allowed, and if the image falls between these lines it satisfies the conditions. This method was introduced recently in a works where gauges had been used for years and had acquired errors. Machines failed to work properly, the cause was discovered, and the projection method convinced men who were loth to believe that the fault lay in over-confidence in a traditional practice.

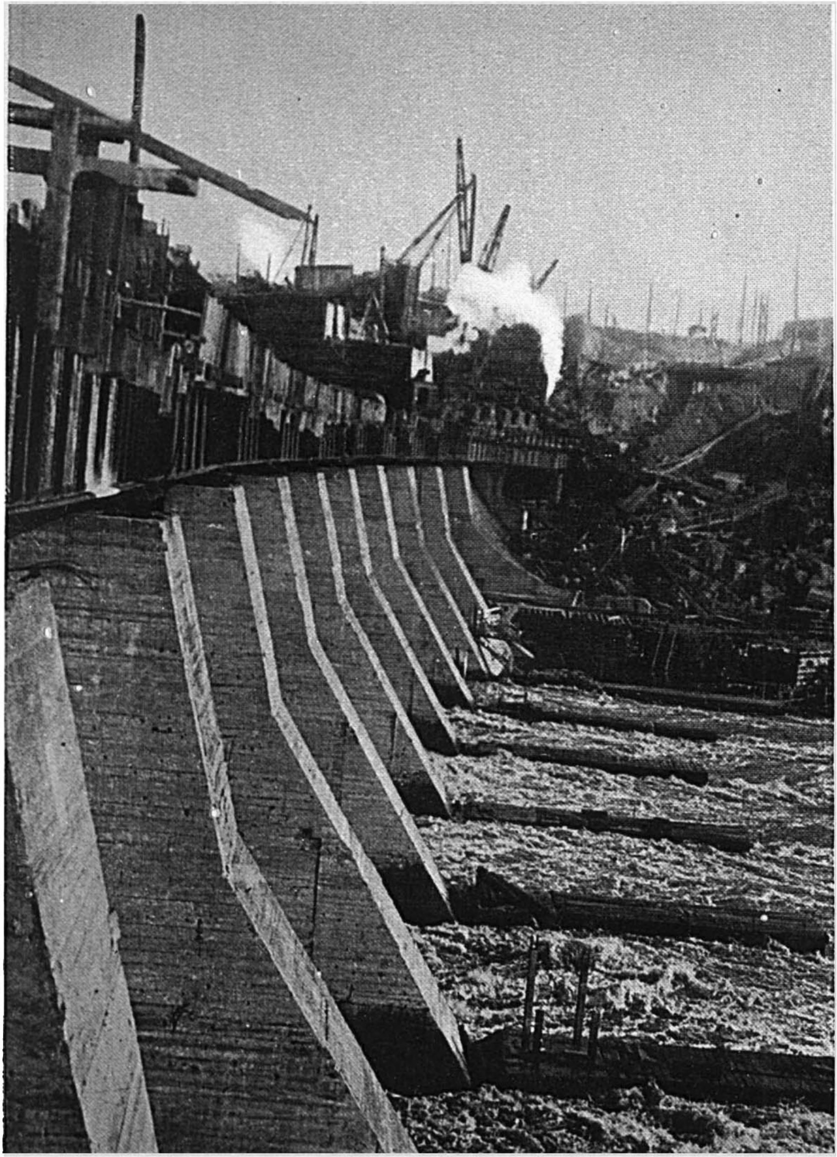
Automatic and semi-automatic machinery has been evolved by making it self-acting, first in respect of one motion, and then in respect of another. It has been built up slowly, one step at a time. For a human being to repeat these motions in exactly the same way required an almost superhuman capacity for taking pains. Few craftsmen possess the delicacy of touch, the patience, and the conscientiousness to produce the parts by the methods in use seventy or eighty years ago. But with artificial aid, accuracy is largely independent of individual human qualities. The machine makes the machine. Operation requires little effort, muscular or mental. It has become machine-minding, and women, girls, and boys have largely replaced men.

How wonderful it is to watch some of these machines at work! Some of them, fed with bar or strip steel at one end, turn out nuts, bolts, screws or washers by the thousand. A big machine is fed with little rods of wood at one end. These are next seen stuck in holes in a travelling belt which winds over pulleys. This belt moves so that the ends of the wooden rods are dipped in hot paraffin wax; then, after an interval for the wax to set, in a composition; and finally delivered as matches neatly packed in boxes. Another machine takes in tobacco and paper and delivers cigarettes, filled, rolled, wetted and sealed almost faster than the eye can follow. The Barber Knotter, used to join up a new set of warp threads to an old warp, will pick up the two threads and tie them together with astonishing accuracy and speed. If it fails once, it does not pass to another pair of threads, but makes a second attempt with the original pair, and with a second failure, a third attempt. After the fourth failure the machine stops, and the operative is called upon to adjust it.

(*Moscow Presse-Cliche*)

NEW SOURCES OF POWER AND MATERIAL

A new and immensely powerful blast furnace in process of completion: Tomsky Factory, Makeevka, Don Basin



(*Moscow Presse-Cliche*)

THE CONQUEST OF POWER

The Dnieper Power Station, Dnieperstroy, in process of construction. All building operations have been mechanised; the capacity will be 810,000 h.p.

Or take another exhibit. The world now consumes more than six hundred million electric lamps every year. The tube from which the bulbs are blown is drawn out continuously from a furnace which operates twenty-four hours a day. A single works may turn out ten thousand miles of tube a year. The machines not only draw the tube but cut it into lengths. Another machine receives the tube and converts it into a bulb ready for receiving the filament.

Automatic machines are not exactly an innovation, but their use received a great impetus during the war. Before those feverish years, the employment of such machines increased only slowly. They were employed for a few articles for which there was a large demand. Men are naturally conservative, and many manufacturers would have continued to follow traditional methods if they had not been forced by military necessity to adopt new ones. One result was relative cheapness of production. Another was the creation of a productive capacity far exceeding the demands of a world at peace and financially crippled.

Millions are unemployed now because a proportion can supply the present needs of mankind. To this issue we shall return later. Here we will throw out a question or so that will reappear for adequate treatment in the later parts of this work. Is this gradual shrinkage of employment to continue, or can the work be spread over a larger number of hands by reducing the hours (or years) of labour, and providing work for all? How will that square with our present business methods? For some chapters these questions must remain floating questions, until we have opened up several new series of considerations that are essential before we can even suggest an answer.