VI

Narrabo igitur primo opera artis et naturæ miranda. . . . ut videatur quod omnis magica potestas sit inferior his operibus et indigna.

ROGER BACON

I do not endeavour either by triumphs of confutation, or pleadings of antiquity, or assumption of authority, or even by the veil of obscurity, to invest these inventions of mine with any majesty. . . . I have not sought nor do I seek either to force or ensnare men's judgments, but I lead them to things themselves and the concordances of things, that they may see for themselves what they have, what they can dispute, what they can add and contribute to the common stock.

FRANCIS BACON (*Preface to the Great Instauration*)

12. THE SCIENTIFIC REVOLUTION

At the opening of the seventeenth century a man of letters, of sufficient genius to be suspected by some of having written the plays of Shakespeare, directed his distinguished literary ability to the promotion and exaltation of natural science. Lord Bacon was the chief herald of that habit of scientific and critical thought which has played so novel and all-important a part in the making of the modern mind. He felt that he had discovered why the human mind, enmeshed in mediæval metaphysics and indifferent to natural phenomena, had hitherto been a stunted and ineffective thing, and how it might be so nurtured and guided as to gain undreamed of strength and vigour.

And never has there been a man better equipped with literary gifts to preach a new gospel than Francis Bacon. He spent years in devising eloquent and ingenious ways of delivering learning from the "discredits and disgraces" of the past, and in exhorting man to explore the realms of nature for his delight and profit. He never wearied of trumpeting forth the glories of the new knowledge which would come with the study of common things and the profitable uses to which it might be put in relieving man's estate. He impeached the mediæval schoolmen for spinning out endless cobwebs of learning, remarkable for their fineness, but of no substance or spirit. He urged the learned to come out of their cells, study the creations of God, and build upon what they discovered a new and true philosophy.

Even in his own day students of natural phenomeua had begun to carry out Bacon's general programme with striking effects. While he was urging men to

cease " tumbling up and down in their own reason and conceits " and to spell out, and so by degrees to learn to read, the volume of God's works, Galileo had already begun the reading and had found out that the Aristotelian physics ran counter to the facts; that a body once in motion will continue to move for ever in a straight line unless it be stopped or deflected. Studying the sky through his newly invented telescope, he beheld the sun spots and noted the sun's revolution on its axis, the phases of Venus, and the satellites of Jupiter. These discoveries seemed to confirm the ideas advanced long before by Copernicus—the earth was *not* the centre of the universe and the heavens were *not* perfect and unchanging. He dared to discuss these matters in the language of the people and was, as every one knows, condemned by the Inquisition.

This preoccupation with natural phenomena and this refusal to accept the old, established theories until they had been verified by an investigation of common fact was a very novel thing. It introduced a fresh and momentous element into our intellectual heritage. We have recalled the mysticism, supernaturalism, and intolerance of the Middle Ages, their reliance on old books, and their indifference to everyday fact except as a sort of allegory for the edification of the Christian pilgrim. In the mediæval universities the professors, or " schoolmen," devoted themselves to the elaborate formulation of Christian doctrine and the interpretation of Aristotle's works. It was a period of revived Greek metaphysics, adapted to prevailing religious presuppositions. Into this fettered world Bacon, Galileo, Descartes, and others brought a new aspiration to promote investigation and honest, critical thinking about everyday things.

These founders of modern natural science realized that they would have to begin afresh. This was a bold resolve, but not so bold as must be that of the student of

mankind to-day if he expects to free himself from the trammels of the past. Bacon pointed out that the old days were not those of mature knowledge, but of youthful human ignorance. " *These* times are the ancient times, when the world is ancient, and not those we count ancient, *ordine retrogrado*, by a computation backward from ourselves." In his *New Atlantis* he pictures an ideal State which concentrated its resources on systematic scientific research, with a view to applying new discoveries to the betterment of man's lot.

Descartes, who was a young man when Bacon was an old one, insisted on the necessity, if we proposed to seek the truth, of questioning *everything* at least once in our lives. To all these leaders in the development of modern science doubt, not faith, was the beginning of wisdom. They doubted—and with good reason—what the Greeks were supposed to have discovered; they doubted all the old books and all the university professors' lecture notes. They did not venture to doubt the Bible, but they eluded it in various ways. They set to work to find out exactly what happened under certain circumstances. They experimented individually and reported their discoveries to the scientific academies which began to come into existence.

As one follows the deliberations of these bodies it is pathetic to observe how little the learning of previous centuries, in spite of its imposing claims, had to contribute to a fruitful knowledge of common things. It required a century of hard work to establish the most elementary facts which would now be found in a child's book. How water and air act, how to measure time and temperature and atmospheric pressure, had to be discovered. The microscope revealed the complexity of organic tissues, the existence of minute creatures, vaguely called infusoria, and the strange inhabitants of the blood, the red and

white corpuscles. The telescope put an end to the flattering assumption that the cosmos circled around man and the little ball he lives on.

Without a certain un-Greek, practical inventive tendency which, for reasons not easily to be discovered, first began to manifest itself in the thirteenth century, this progress would not have been possible. The new thinkers descended from the magisterial chair and patiently fussed with lenses, tubes, pulleys, and wheels, thus weaning themselves from the adoration of man's mind and understanding. They had to devise the machinery of investigation as investigation itself progressed.

Moreover, they did not confine themselves to the conventionally noble and elevated subjects of speculation. They addressed themselves to worms and ditch water in preference to metaphysical subtleties. They agreed with Bacon that the mean and even filthy things deserve study. All this was naturally scorned by the university professors, and the universities consequently played little or no part in the advance of natural science until the nineteenth century.

Nor were the moral leaders of mankind behind the intellectual in opposing the novel tendencies. The clergy did all they could to perpetuate the squalid belief in witchcraft, but fonnd no place for experimental science in their scheme of learning, and judged it offensive to the Maker of all things. But their opposition could do no more than hamper the new scientific impulse, which was far too potent to be seriously checked.

So in one department of hnman thought—the investigation of natural processes—majestic progress has been made since the opening of the seventeenth century, with every promise of continued and startling advance. The new methods employed by students of natural science have resulted in the accumulation of a stupendous mass of information in regard to the

material structure and operation of things, and the gradual way in which the earth and all its inhabitants have come into being. The nature and workings of atoms and molecules are being cleared up, and their relation to heat, light, and electricity established. The slow processes which have brought about the mountains and valleys, the seas and plains, have been exposed. The structure of the elementary cell can be studied under powerful lenses; its divisions, conjunctions, differentiation, and multiplication into the incredibly intricate organization of plants and animals can be traced.

In short, man is now in a position, for the first time in his history, to have some really clear and accurate notion of the world in which he dwells and of the living creatures which surround him and with which he must come to terms. It would seem obvious that this fresh knowledge should enable him to direct his affairs more intelligently than his ancestors were able to do in their ignorance. He should be in a position to accommodate himself more and more successfully to the exigencies of au existence which he can understand more fully than any preceding generation, and he shonld aspire to deal more and more sagaciously with himself and his fellowmen.

13. HOW SCIENTIFIC KNOWLEDGE HAS REVOLUTIONIZED THE CONDITIONS OF LIFE

But while our information in regard to man and the world is incalculably greater than that available a hundred, even fifty years ago, we must frankly admit that the knowledge is still so novel, so imperfectly assimilated, so inadeqnately co-ordinated, and so feebly and ineffectively presented to the great mass of men, that its *direct* effects upon human impulses and reasoning and outlook are as yet inconsiderable and disappointing. We *might* think in terms of

molecules and atoms, but we rarely do. Few have any more knowledge of their own bodily operations than had their grandparents. The farmer's confidence in the phases of the moon gives way but slowly before recent discoveries in regard to the bacteria of the soil. Few who use the telephone, ride on electric cars, and carry a camera have even the mildest curiosity in regard to how these things work. It is only *indirectly*, through *invention*, that scientific knowledge touches our lives on every hand, modifying our environment, altering our daily habits, dislocating the anciently established order, and imposing the burden of constant adaptation on even the most ignorant and lethargic.[1]

Unlike a great part of man's earlier thought, modern scientific knowledge and theory have not remained matter merely for academic discourse and learned books, but have provoked the invention of innumerable practical devices which surround us on every hand, and from which we can now scarce escape by land or sea. Thus while scientific knowledge has not greatly affected the thoughts of most of us, its influence in the promotion of modern invention has served to place us in a new setting or environment, the novel features of which it would be no small task to explain to one's great-great-grandfather, should be unexpectedly apply for up-to-date information. So even if modern scientific *knowledge* is as yet so imperfect and ill understood as to make it impossible for us to apply much of it directly and personally in our daily conduct, we nevertheless cannot neglect the urgent effects of scientific *inventions*, for they are constantly posing new problems of adjustment to us, and sometimes disposing of old ones.

Let us recall a few familiar but none the less im-

[1] See the present writer's *Humanizing of Knowledge* (1923) for a fuller discussion of this matter.

portant examples of the astonishing way in which what seemed in the beginning to be rather trivial inventions and devices have, with the improvements of modern science, profoundly altered the conditions of life.

Some centuries before the time of Bacon and Galileo four discoveries were made which, supplemented and elaborated by later insight and ingenuity, may be said to underlie our modern civilization. A writer of the time of Henry II of England reports that sailors when caught in fog or darkness were wont to touch a needle to a bit of magnetic iron. The needle would then, it had been found, whirl around in a circle and come to rest pointing north. On this tiny index the vast extension of modern commerce and imperialism rests.

That lentil-shaped bits of glass would magnify objects was known before the end of the thirteenth century, and from that little fact have come microscopes, telescopes, spectroscopes, and cameras; and from these in turn has come a great part of our present knowledge of natural processes in men, animals, and plants and our comprehension of the cosmos at large.

Gunpowder began to be used a few decades after the lens was discovered; it and its terrible descendants have changed the whole problem of human warfare and of the public defence.

The printing press, originally a homely scheme for saving the labour of the copyist, has not only made modern democracy and nationality possible, but has helped by the extension of education to undermine the ancient foundations upon which human industry has rested from the beginnings of civilization.

In the middle of the eighteenth century the steam engine began to supplant the muscular power of men and animals, which had theretofore been only feebly supplemented by windmills and water wheels. And now we use steam and gas engines and water power to generate potent electric currents which do

their work far from the source of supply. Mechanical ingenuity has utilized all this undreamed-of energy in innumerable novel ways for producing old and new commodities in tremendous quantities and distributing them with incredible rapidity throughout the earth.

Vast factories have sprung up, with their laborious multitudes engaged on minute contributions to the finished article; overgrown cities sprawl over the neighbouring green fields and pastures; long freight trains of steel cars thunder across continents; monstrous masses of wealth pile up, are reinvested, and applied to making the whole system more and more inconceivably intricate and interdependent; and incidentally there is hurry and worry and discontent and hazard beyond belief for a creature who has to grasp it all and control it all with a mind reared on that of an animal, a child, and a savage.

As if these changes were not astounding enough, now has come the chemist who devotes himself to making not new *commodities* (or old ones in new ways), but new *substances*. He juggles with the atoms of carbon, hydrogen, oxygen, nitrogen, chlorine, and the rest, and far outruns the workings of nature. Up to date he has been able to produce artfully over two hundred thousand compounds, for some of which mankind formerly depended on the alchemy of animals and plants. He can make foodstuffs out of sewage; he can entrap the nitrogen in the air and use it to raise wheat to feed, or high explosives to slaughter, his fellows. He no longer relies on plants and animals for dyes and perfumes. In short, a chemical discovery may at any moment devastate an immemorial industry and leave both capital and labour in the lurch. The day may not be far distant when, should the chemist learn to control the incredible interatomic energy, or penetrate the secret of photosynthesis, carried on by the green leaf, the

steam engine will seem as complete an anachronism as the treadmill.

The uttermost parts of the earth have been visited by Europeans, and commerce has brought all races of the globe into close touch. We have now to reckon with every nation under heaven, as was shown in the World War. At the same time steam and electrical communication have been so perfected that space has heen practically annihilated as regards speech, and in matters of transportation reduced to perhaps a fifth. So all the peoples of the earth form economically a loose and, as yet, scarcely acknowledged federation of man, in which the fate of any member may affect the affairs of all the others, no matter how remote they may be geographically.

All these unprecedented conditions have conspired to give business for bnsiness' sake a fascination and overwhelming importance it has never had before. We no longer make things for the sake of making them, but for money. The chair is not made to sit on, but for profit; the soap is no longer prepared for purposes of cleanliness, but to be sold for profit. Practically nothing catches our eye in the way of writing that was written for its own sake and not for money. Our magazines and newspapers are our modern commercial travellers proclaiming the gospel of business competition. Formerly the labouring classes worked hecause they were slaves, or because they were defenceless and could not escape from thraldom—or, mayhap, because they were natural artisans; but now they are coming into a position where they can combine and bargain and enter into business competition with their employers. Like their employers, they are learning to give as little as possible for as much as possible. This is good business; and the employer should realize that at last he has succeeded in teaching his employees to be strictly business-like. When houses were built to

live in, and wheat and cattle grown to eat, these essential industries took care of themselves. But now that profit is the motive for building houses and raising grain, if the promised returns are greater from manufacturing automobiles or embroidered lingerie, one is tempted to ask if there are any longer compelling reasons for building houses, or raising food?

Along with the new inventions and discoveries and our inordinately pervasive commerce have come two other novel elements in our environment—what we vaguely call "democracy" and "nationality." These also are to be traced to applied science and mechanical contrivances.

The printing press has made popular education possible, and it is our aspiration to have every boy and girl learn to read and write—an ideal that the Western World has gone far to realize in the last hundred years. General education, introduced first among men and then extended to women, has made plausible the contention that all adults should have a vote, and thereby exercise some ostensible influence in the choice of public officials and in the direction of the policy of the government.

Until recently the mass of the people have not been invited to turn their attention to public affairs, which have been left in the control of the richer classes and their representatives and agents, the statesmen or politicians. Doubtless our crowded cities have contributed to a growing sense of the importance of the common man, for all must now share the public conveyance, the water supply, and contagious diseases.

But there is a still more fundamental discovery underlying our democratic tendencies. This is the easily demonstrated scientific truth that nearly all men and women, whatever their social and economic status, may have much greater possibilities of activity

and thought and emotion than they exhibit in the particular conditions in which they happen to be placed; that in all ranks may be found evidence of unrealized capacity; that we are living on a far lower scale of intelligent conduct and rational enjoyment than is necessary.

Our present conceptions of nationality are of very recent origin, going back scarcely a hundred years. Formerly nations were made up of the subjects of this or that gracious majesty and were regarded by their God-given rulers as beasts of burden or slaves or, in more amiable moods, as children. The same forces that have given rise to modern democracy have made it possible for vast groups of people, such as make up the British Empire, France, or the United States, to be held together more intimately than ever before by the news which reaches them daily of the enterprises of their government and the deeds of their conspicuous fellow-countrymen.

In this way the inhabitants of an extensive territory embracing hundreds of thousands of square miles are brought as close together as the people of Athens in former days. Man is surely a gregarious animal who dislikes solitude. He is, moreover, given to the most exaggerated estimate of his tribe; and on these ancient foundations modern nationality has been built up by means of the printing press, the telegraph, and cheap postage. So it has fallen out that just when the world was becoming effectively cosmopolitan in its economic interdependence, its scientific research, and its exchange of books and art, the ancient tribal insolence has been developed on a stupendous scale.

The manner in which man has revolutionized his environment, habits of conduct, and purposes of life by inventions is perhaps the most astonishing thing in human history. It is an obscure and hitherto rather neglected subject. But it is clear enough, from the little that has been said here, that since the Middle

Ages, and especially in the past hundred years, science has so hastened the process of change that it becomes increasingly difficult for man's common run of thinking to keep pace with the radical alterations in his actual practices and conditions of living.

§ VII