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When I joined the Faculty of the University of California, I found there an eminent Sanskritist, a great scholar and a man of great tenderness and a great sense of irony and sorrow and I studied Sanskrit with him, not very much, and from time to time he would say to me, "If your science were any good, it would be much easier to get an education now than it used to be". Well, there's something wrong with that picture as all of us who either have tried to get an education or to help others know, because his image was that of a world of knowledge which was essentially closed and the more you learned, the less there was to learn; the more was left to learn, the more you learned, the more things hung together and the better an education would be. The world of science and the world of knowledge is not like that. Everything that we learn seems to open it wider and wider and the very act of knowing seems to get us into strange territory. And it's very much more our feeling like that which Newton had when he said, reflectively, when people insisted that he had made the greatest and most violent discoveries of all time, no, he was a small child digging up a few pebbles beside the ocean of truth. Newton understood that what he had started was indeed a world of endless action. This was not perhaps true of the high middle ages insofar as their view of the world of nature. But their preoccupation was so overwhelmingly with the supernatural world that the closure of the world of nature was for a while tolerable. This has its happy aspects and I hope some of the illustrations to which we will come tonight will seem as happy to you as they do to me. And this notion of an essentially open and unfolding growth of knowledge and with it, of capacity, characterizes the enlightenment and is the most substantial objective element in the idea of human progress. If one thinks of the arts, if one thinks of such deep and essentially persistent questions as the quality of life and of virtue, it is hard to see what progress can mean, in that most of us look 2,000 years back for the highest examples of virtue, and many of us look 2,000 years back for the highest examples of arts but with knowledge, it's different. It grows, and although the men who do it don't get any better, the product gets bigger and the product gets lovelier and it's clear that men do to-day what couldn't be done before, that their powers, in some sense, have grown. This leaves us with the problem which I am going to leave quite untouched tonight, and to which I will return, Thursday, of the relation between the rapid forward motion of one part of the human effort and of human life and the response of those who by profession as philosophers, as writers, as statesmen, live in a situation which is deeply affected by the progress of knowledge, the growth of knowledge, but which does in a certain sense inherently not partake of it. The development in European culture about which we're talking is not, I think, really understood by historians, but everyone seems to agree that it came about by the confluence of two things each of which, is, in human history, almost a miracle. The first, and I believe it is a necessary if not at all a sufficient condition for the growth of knowledge, for this explosive and wonderful growth, is the idea, first clearly exemplified, first clearly articulated in Greece, that one could prove something, that one could make a connection between propositions which had a kind of necessity which couldn't be monkeyed with because this has given to knowledge an element of coherence so that if something goes wrong, a big chunk of knowledge is involved and there are ways to find out how it has gone wrong, and why and in what sense. If everything is related to everything else only by arguments of plausibility and analogy and you suddenly find that you have a contradiction, all the links in the chain are flexible and it is very hard to get your hands on it. But if the links in the chain have the rigidity, the idealized rigidity of Euclid, or some mock-up of it which is more likely, you have a possibility of finding out what is wrong. And the second which was present certainly in the Greek world, and to an extent which is only just being understood, hardly understood, by persons as Archimedes, is the other trait of trying things out, trying things out either as an experiment or more naturally in an attempt to make something, in an attempt to solve a practical problem, and you know how Archimedes exemplifies both aspects of this. The confluence of these in the rediscovery of antiquity grew in European soil and has been nourished by two disparate motives for the growth of science, disparate in the sense that I have never been able to reduce one to the other, I have never been able to say that we would be where we are if we had had one and not the other. I have my preferences, but I can hardly expect that they will be generally shared. I can make this point by going quite far back by quoting a very famous two paragraphs from Hobbes. They are extremely sharp and I ask you to remember that they were written just a few years before the publication of the *Principia* of Newton. Hobbes is going over the things that make for power and he says, "The Sciences, are small Power; because not eminent, and therefore, not acknowledged in any man; nor are at all, but in a few; and in them, but of a few things. For Science is of that nature, as none can understand it to be, but such as in a good measure have attayned it." Arts of public use as fortification, making of engines, and other instruments of war because they confer to defence, and victory, are power and though the true mother of them be science, namely the mathematics, yet because they are brought into the light by the hand of the artificer, they be esteemed, the midwife passing with the vulgar from the mother as his issue. This is very much the situation in which we are, for it is the atomic bomb that brought science prominently into the public mind which has very little to do with science, more than Hobbes thought, but it is a very modern example. For these two traits can easily be over-purified and I will do that. I think we shouldn't make it too simple. One kind of motivation and you have to look not at the object of study but at the purpose of study. You can't say that the study of a certain kind of problem inevitably means that you know why it is being studied. Sometimes you can. One kind of motivation is natural, human, not by any means universal. It comprises everything from a desire really to understand, revel, cognoscere causes, to get at the root of things, on the one hand, to a desire to be inventive, to try things out, to be impertinent and to try things that are new, to be adventurous, to explore. It can be stimulated by a new discovery because almost always a new discovery settles something, but it unsettles a great deal more, it raises many more new questions than it has answered. It can be stimulated by new gadgetry which offers a new possibility of asking questions, a new machine, or a new tool. Such was the role of the telescope in the formative years of European science. It can be stimulated by a new opportunity. We have one today of putting a telescope outside the earth's atmosphere and having a better look at the heavens. It can be stimulated, and very often is by an unresolved paradox, by something that is either a contradiction or just a hair's breadth away from a contradiction, which indicates that there is gold in the problem, that it isn't in order, that there is something more to be discovered. And of course, no cases are known which have remained paradoxes very long, though at any moment, as today, the field of science is full of them and they are just the cracks where we are trying to get our chisels in and see what's underneath. This is the science of fact and motivation and it wouldn't be credible and it wouldn't be honest for me not to say that it seems to me a very high and precious human quality. But discovery can be stimulated also by much more pedestrian things, and in the history of science this has played a large part. This is the desire that people have for what in general terms may be called a product or a basis for products. A great deal of the money that is spent in our today's world is for study, and one hopes discovery, for research and development, that is applied and intended to answer practical questions. We'd like a material that combines the strength of steel, the lightness of paper, the transparency of glass, and you can go to the laboratory and say, "here's a certain amount of money, do what you can about it!". It actually turns out that impractical motivation, motivation concerned solely with knowledge, very often pays off in practical ways, traditionally./ does. It may not be that everything that is discovered is useful, but it is so that most things that are discovered are contiguous to and continuous with things that are useful. It's hard to find an example but it can be done, of branches of science, small branches of science, which have so far to our knowledge not directly produced any dollars or any pounds. Very often it may be that a technique, a mathematical or experimental technique, developed for a useful purpose turns out to be enormously helpful in advancing useless science. Radio astronomy is really a war-born technique and a great deal of the work one does with radioactive tracers and with other tracers, to study fundamental biological processes is a by-product of the atomic industry of the war. Today these two disparate and quite unrelated motives for the growth of science, for discovery, coexist and the interaction between the two is very great. That is relatively new. I think that it came to be accepted, really, with the development of electricity, which, as you know, grew out of the most pure and abstract and lovely speculations and experiments, initially, perhaps of Faraday and very rapidly became, within a century, a source of very important practical applications. But the 19th century still saw decisive inventions, steam engine, cotton gin which didn't have anything to do with new knowledge at all, which could have been made earlier if people had a good motive for it. And the great motive power in the scientific revolution of the early Renaissance and above all the late Renaissance, of the 13th century and the 17th century, was not technological, it was almost wholly speculative, philosophical, ruminative. It was only later that the things changed. I suppose that the last important example of an invention which doesn't have something to do with new knowledge, which isn't fed by the growth of science, is the zipper. There may be another one, but that's the last one I know of! today, anyway, the two are very much mixed up and in a double sense with the result that it is hard even for the discerning student who is not actually living in the — scene to know which studies are born of the love of nature and hope of understanding nature and which are born of an attempt to satisfy some need, real or fancied, deep or superficial, practical human needs to make a profit, contribute to weaponry or will enlarge the possibilities of communication. The fructification of science by technology is comparable in its importance today to the fructification of invention and technology by science. It is my opinion that when it comes to finding out deep things of nature, the goal of wanting something out of it is not as productive as the goal of taking advantage of what has been learned, what has been made, of new techniques, of new knowledge, to put sharp, — new — questions of nature, to create situations which never existed before, as situations suitable for human study, to act on nature and from that to learn. It wasn't much use for the alchemists and their patrons to want to make gold. That never made gold and by the time gold was made, nobody wanted to make it. I believe that much the same thing will be true from the study of living things, from the study of men. The motives which we now deduce for thinking that that may be a good thing, because it would help us in a practical way are probably quite far from the motives which will get us there in time. These questions that we'd like answered will be responsive to new techniques of psychologists and biologists and they may answer questions which don't seem to us at all interesting, which don't tell us what we really want to know. In time we will learn as we have in the more aged and familiar sciences, that even the questions which seemed uninteresting, once answered, are the basis of very great changes and of very important, I hope, improvements, in the human condition. I will not labour the fantastic feed-back of technology into scientific work but I do want to emphasize that there is a tension between these two motives which increasingly are symbiotic, science for utility and science for understanding, and knowledge for power on the one hand or knowledge as an end in itself, and this tension shouldn't be glossed over. It's there and one, I believe, cannot simplify past history or future hopes by ignoring one or the other. Indeed, in trying to help the parts of the world in which science is not rooted and which are typically also very poor, we should keep this bivalence in mind and neither insist that the young man from south-east Asia should interest himself exclusively in the immediate practical problems of his country nor insist that he ignore these problems and take fire with the love of knowledge which his professor may happen to have. I want to turn to a few examples of knowledge where discovery has action because I fear that if I talk only in abstract terms, it may be not entirely clear. I know that many of you have seen new knowledge discovered and have done it yourselves but not all of us have had that, and I am going to give some examples of new knowledge picked at random because I happen to have heard of them, but not quite at random. They all have in common this active quality which seems to me so decisive and which is quite falsified by Newton's boy because his action was just to pick up pebbles. That's very much less than

Newton did. They all have in common that they throw some light on such strange words as 'objectivity' and ' necessity'. They throw some light on what it is that makes science objective, as compared, let us say, to law. I have only good words to say for law! And they, I think, throw a light on it that is quite unexpected, that certainly no one in the 18th or 19th Century would have imagined. They all have in common the fact that something quite new and unexpected turned up in a place where there seemed to be no special reason to look for it. They all have in common that they give a much subtler view of the meaning and scope and limit of the idea of necessity in nature, than, let us say, LaPlace or even Maxwell would have held, and they all have in common that they illustrate in one way or another the fact that perception, knowledge, information are always gained at a cost, that they are gained by an act of choice which makes it simultaneously impossible to pursue other courses which might have revealed other things. But in other respects, they are very different. The first four are really very primitive experiments. They seem to me they could have been done by Pascal, if he had thought of them for certainly the equipment involved is of the most, most elementary. They all lie in fields which are very close to our common experience so that I will expect you will feel as I do that this has something to do with you and has something to do with life and ordinary experience. They are all quite recent and I mean to emphasize particularly, they are all things about which I don't know very much. I have read about them but I am talking to you about them essentially as, I hope, an honest but anyway a not very deep journalist. The fifth is from my own field and you'll find it extremely much harder to understand whereas in the case of the first four I will tell you, if not everything I know, at least a finite fraction of what I know, the rest will be maybe twice as much but not ten times as much. In the case of the example in my own field, I will just tell you a minute fraction of what I know and I am sure I understand it very well. My troubles are all in making it clear to you, not in making it clear to me! But the fifth example is in some ways the deepest and it is one that is, I believe, certainly worth my effort and I hope worth yours to hear about a little bit. The first is, well the order does not have any great significance, except the first four are different from the fifth. The first is an experiment conducted by Jean Bancaud, a very great neuro-physiologist in Paris. This is an experiment which may have been done on many primates but in the version that I saw it, it was done with dogs and like all primates, the dog's auditory nerve consists no doubt of many other things but at least of two things that are quite different in appearance, rather large bundles of nerves, of which it has not unreasonably been thought that they brought the disturbance from the inner ear to the cortex and were indispensible in bringing to the cortex some record of the sound that the ear was supposed to hear. Then there are other fibrils which are of much smaller diameter and I believe that for a long time it was supposed that they brought small sounds to the cortex but I'm not sure! In any case, Bancaud found out. He hooked up a micro-electrode to the larger fibrils and found, to I think no one's great surprise, that a dog who heard a bell would give a characteristic pattern of electrical current which was essentially repeatable, I don't mean from dog to dog, although even that is partly true, but from bell to bell and this signal was a good indication that the dog was hearing the bell! But now, something very remarkable happened which has to do with the word animadversion only it isn't in this case the right word. It isn't the anima that is adverted. If the dog had the bell rung with one small change in the arrangement then something different happened. The small change was that there be a piece of meat within whiffing distance. Then the bell could ring, the electrode could be in the auditory nerve but no current passed through it. And the function of the small fibrils of nerves is apparently to take to the sense organ, in this case, the ear, coding instructions as to how the ear is to behave. It is not to pay any attention to the sounds so the dog can enjoy his meal! This is a very simple experiment. It shows at once that such data in the sense in which they have been talked about by philosophers and ordinary men as the foundation of our knowledge of reality, are themselves enormously complex artifacts, determined not just by the simple physics of the receiving system but by the degree of inherent and purposeful intelligence which adapts the, in this case, canine, in our case, human organism, to the situation on the basis of some rather total judgment of what the situation is and what it is appropriate to hear and what it's appropriate not to hear. It is quite clear that this is an example of a primitive and thoroughly unphilosophical and uncomplicated way that the dog's ability to hear the bell was given him when he was not actively involved with the meat and it was taken from him when he was actively involved with the meat. And this is rather the prototype of the situation in which we gather knowledge, even in perception, quite apart from active, planned experiments, quite apart from the role of tradition in determining how we think of things, even in perception, and even in an organism not as verbose as we, at the cost of losing other knowledge. The second set of experiments was done by a group of psychologists in Canada of whom, I think the principal student, principal scientist was Hebb. They were done at McGill and I believe that initially their purpose was to make some dent on the question 'what goes on in brain-washing?' because they originated during the harsh days of the Korean War. Before answering this question, the psychologists decided that they would like to find out what happens when nothing happens, that is, if you take a man and don't ask him questions and don't shine a bright light in his face and don't starve him to death and don't keep him awake for thirty hours, what goes on then? It was good that they asked the question because what went on then was not exactly what I would have guessed. They picked, I believe, people they regarded as normal, medical students, and such! And the results were not utterly independent of the medical student, people behaved in a little different way, but the essential differences were that some people had nothing done to them for longer than others and the definition of doing nothing is not entirely perfect. They took their patients, or victims, and put them in a room which was quite well sound-proofed and in order to prevent the sounds from filtering in that might have been interesting, they had a kind of hum go on all the time which blanked out the sounds. They put ground-glass goggles on so that they couldn't see. They put cuffs of card-board over the fingers and stuffed them with cotton batting so they couldn't feel and they generally gave them very bland food and laid them down on a bed and said, 'now go think and solve that problem that you haven't had time to solve' and left them there for varying periods. The longest period, I believe, was perhaps six days, and typically the periods were two days but shorter ones did occur. The food was deliberately bland. Everyone who was asked to do this said, 'wonderful, I've never had a chance to think properly and uninterruptedly' and the volunteers were abundant. And everyone liked it at first. But as time passed it clearly took on another and very different character. People who came out after a few hours were just dandy, people who came out after twelve hours were a little odd but they said that they hadn't been thinking clearly for the last six hours! People who stayed in a day or two days, six days or anything like that came out with impairments of a different character from those I would have expected. The impairments were, as far as I know, temporary, and everybody got well, and the length of time of recovery had some relation to how long they were in difficulties. They were unable to add and subtract, they couldn't use words properly, they couldn't identify physical objects properly because the integration needed to see in perspective was missing. They lost the higher rational function, I will not say totally, but in a very, very great respect. This seems to be because memory requires something that we didn't know about. One always thinks of memory as one of these storage bins like our own offices where we have drawer after drawer of items of information and when you want one you try to remember where it is and pick the wrong drawer and then you go to the right one and there it is and out it comes. But it has a dynamic quality. It seems to require something that these steel filing cases don't require. It seems to require a constant traffic, it seems to require constant activity. The second is a discovery and a non-trivial one, it seems to me that compared with most psychological investigations, this really turned out something about the nature of memory which men did not know. It suggests again how high a level of activity is required, not in this case primarily for perception, although perception went to pieces in this experiment. But how high a level is required even to keep available the resources which our experience, our education and our conscious life have given us. A slightly different kind of experiment was conducted by Barnes at Harvard and I don't know whether this one is really so amazing. He made sequences of sounds, not arbitrary sounds, but things that are called phonemes, namely the elements of sound that appear in speech and tried these out on two sub-populations, one were Harvard students, and Radcliffe, and one were Navajo Indians. And the questions that he asked were the same. He said, 'how many different phonemes, how many different sounds do you hear.' Now, of course, all sounds are different, and the intention of the question it was explained was different in the sense that you would discriminate between these, as if they were parts of speech, indicating a different word or a different meaning. And it turned out that the two sets of answers were quite consistent in all this, subject to trivial error, counted the same number of phonemes. But the two groups didn't count the same number at all, because in two languages the criterion of a separate symbolic meaning is very different. We pay great attention to the quality of our vowels in the sense that 'i' and 'e' will make different phonemes. The Navajo pays great attention to the length of the vowel in the sense that 'i' and 'e' is relatively trivial, as the length would be for us. But it was possible to teach each group to do it the other way but it was not possible to teach any group to keep both methods of discrimination working at the same time! The last of these really household examples is by far the most beautiful, I think, and it is also a good example of an experiment of which I cannot say whether it was done for the sordid purpose of making millions or for interest in some phenomena of nature because it was conducted by Land who is a scientist of great ingenuity and discernment but is also head of the Polaroid Corporation, and as you undoubtedly know better than I, it would be very nice for the Polaroid Corporation if they could make good colour film which could be cheaply marketed and could be developed as can their black and white film in a matter of a minute so that you see the picture just after you've taken it. Land did not one experiment but a whole series and they have been published in a good deal of detail in the learned journals and a reasonable summary of them has been published in a more popular journal and I don't believe that I would like to tell you more than just one experiment which has the nub of the thing in it and which has the shock. The normal theory of colour vision which has probably some truth in it is that the eye has in it a way of responding, the retina has, and specifically the rods, to probably three different bands which would correspond to light of different wave-length and colour. The popular ones are red, blue and yellow but there have been variations and arguments about this. And that the eye and the cortex together somehow conspire to assay the amount of these colours that is in the light and then to reassemble the colours and make an orange or a green or a violet in a proper way that will correspond by definition with the visual image of the coloured object. As I say, there may be a lot of truth in this and there is nothing at all in what Land did that disproves it. If you do your work with single colours, a little circle of red or yellow or blue, you get confirmation of this. But Land did not do that. He took a multicoloured scene. There is not a meaningful thing in this scene, the colours don't correspond to the shapes or locations. They are actually, I believe, just a bunch of chemicals lying around in jars. But there is a wide variety of colour, blue, green, yellow, orange, red, purple. And then he did the following. He took two photographs of this multicoloured scene, one with a sodium line which is in the yellow. He printed that black and white. Then he took another picture of the same scene with a yellow light, also pretty monochromatic and almost the same shade of yellow, removed 200 Ångstroms, the general spread of the visible spectrum is about 4,000 Ångstroms, so this is a very small fraction, five per cent or something like that, of the range of different wave-lengths we respond to, almost identical yellows and I am sure that I would not know which was which if I were shown one and spent five minutes and then shown another, I wouldn't know whether I were seeing the same one or another. He made a black and white image of that picture. Then he reprojected these two black and white images, each with the same yellow light by which the black and white picture had been taken and superimposed them so that you saw the combined two yellow images of black and white pictures. That's what you should have seen but what you do see is blue, green, yellow, orange, red and the full spectrum of the original picture. This shows that however much you may be aided in seeing by the presence of a wide range of wave-lengths, a very small clue as to the integral spectral quality that you get from the relative difference of intensity that these two almost indistinguishable yellow lights give is enough for the eye and the cortex combined to give you a perception of colour. I think that the sense datum looks funnier and funnier after that. Now it is true that in this experiment the impression of colour is not absolutely faithful and not absolutely vivid. You see green but it isn't just the green you would see if you looked at the thing with white light. You see red, the red is slightly off colour. As soon as you move these two spectral lines apart aways or use white and one spectral line you see it just as well as though you had a complete colour image. It's only the extreme proximity of the two yellow lines that limits it. Here again it seems to me that we understand how very organised and active a part our organs of perception play in the simplest of our experiences because here you are seeing red, there is a red object out there, but there is no red light travelling from the object to you to tell you about it. It means that we cannot mean by objectivity that there is a clear, unique physical connection between the thing we see and our image of it or the thing we hear and our image of it. It means that some quite different definition of objectivity is going to be required. It also means, as I have said before, that every act of perception is purchased at a cost. I want to come to my other piece of discovery, it's a lot harder to tell about, which bears just on these questions of the element of choice in our study of reality, of the element of objectivity in what we find and the need for a fresh definition of it, of, not as naive and more applicable, if you wish, more in accordance with the pragmatic view that a definition of objectivity should somehow enable us to discover whether a piece of information is or isn't objective and which also throws a very great light on the existence in nature, not of a chance which we're familiar with and always have ascribed to the fact that things were too complicated for us to study in enough detail or too remote in time for us to study in enough detail, to follow fully the course of events. This is a kind of chance which could not be obviated even by our longevity or our greatest industry, a kind of chance which is inherent in the world which is not conferred on it by our behaviour and all that is conferred on the world by our behaviour is that we know something. We know enough to make intelligent predictions but not certain predictions, not predictions of certitude but predictions of probability. This all is in most striking contrast to a view of the nature of knowledge and of the world, a little frivolously but not without historical warrant attributed to LaPlace. And it is a view which, in important respects, Einstein shared. I think that it starts by the assertion that in a relevant and meaningful way the world is there for us to look at and study, that we can find out all about it - this is an idealization. We won't ever find out all about it. But we can find out, we can approximate this, to any degree of which is worth our while, and that the givenness of the world is what constitutes its objectivity and our ways of studying it may be more or less clever, more or less appropriate but they have nothing to do with what we find but only with the ease and skill with which we find it out. LaPlace, you remember, put forward the view that since Newton's laws were so fine if one knew where everything was and with what velocity it was moving, the whole future could be predicted by a good enough mathematician. This has always seemed rather dull to me because the idea of knowing all this is so inhuman anyway that you might as well know the future to begin with. But quite apart from that, I think the importance, one of the importances, of the development in this century in physics is not that it has shown that this is not a very practical undertaking, that one knows, but shown something much deeper, shown that it is a false ideal of human knowledge and that the true ideal is a much richer one, and much easier to live with, and very much more like our situation, in other parts of human life where we're concerned, with judging, with committing ourselves, with loving, not primarily with knowing. This very great change in physics of course started in action, and the historic beginnings of it were also taken in Canada by Rutherford when he turned from regarding the radiations from radioactive substances, as interesting phenomena to study and observe, and turned them into tools by hurling these radiations, he didn't hurl them, he let them hurl themselves, on atoms and discovering what happened in this encounter. These are ordinary atoms, not nuclear atoms, the atoms of which chemicals are made, and the whole story I am going to tell was developed out of the study of atomic mechanics, it's applicable to nuclei and atomic nuclei, but it wasn't discovered there and isn't much illuminated by anything that happens there. The problem that Rutherford posed was the discovery of what was in an atom, a central nucleus, in the case of hydrogen, of course, a proton, and in the case of hydrogen, just one electron going somehow attached to it. This he found and then the question was how to try to understand what was going on in an atom because in no way did the electron and the nucleus, the proton, behave like the earth and the sun, like a solar system, although the electrical forces between them were very similar and practically identical, except in magnitude to the gravitational forces of Newton. Now, I can't tell the story in full historic detail, it's a very tangled story in the history of ideas and already starts with things of horrifying sophistication which turn out not to have been essential, logically, but were essential, historically. But I will try to indicate why what was found and how it bears analogically on some of the great human questions, like the question, 'is this a situation where we should understand what has happened in terms of nature and the necessity of its happening as we try for instance in the case of a man's illness, or is this a case in which we should try to assess whether we are dealing with good or evil, as we do in the case of most of a man's actions?' Almost the first thing that happened and the first that I find simple enough to talk about is the discovery of discreet nature of light when it is absorbed or emitted, finite amounts of energy in proportion to the frequency appear or disappear. Einstein discovered this and discovered many of the other things which come next, but in the end he didn't like the result and he wouldn't buy it! Then in studying the nature of these individual atoms of Rutherford, Bohr, confronted by the total failure of the analogy with the planetary system, had a radical idea which was to prove right and to be enormously deepened. The idea is this, that normally, when not interacting, an atom exists not in terms of the orbit of electron rotating around the proton, but of something new and different, something that he called the stationary state. This is not the state in which anything changes with time, it is not the state in which you can say the electron is here and it flits around there. It is something, as Bohr introduced it, outside the description of the classical motion of particles. If there is any kind of disturbance, the atom may move from one stationary state to another and the intervals at which it does this are subject to statistical laws, that is, you can say half of them will have done it in a hundredth of a microsecond, you can't say which atom will do it at which time. And what's more, these changes from one stationary state to another, even less than the stationary states themselves are not a form of motion, they are changed with time but you can't say what goes from where to where. They are again quite outside the framework of any old-fashioned ideas of motion. We had in the atom a situation that was quite unlike the familiar world of mechanics. It turned out that just as in the case of light, we had to do with a very deep point but in the case of light, the discovery of its corpuscular character being like a particle, in no way supplemented the centuries of experience that it is a wave, that it can interfere, that it defracts around obstacles, that the sum of two waves can be more than the sum, or less than the sum, depending on the phase relations between the waves, that is, the sum of the intensities, can be either zero or twice if not two equal one. All these things are true, were true, couldn't be made untrue by any new findings, and so, a double character of light. The turning point was the discovery that Bohr's stationary states were also, though they referred to what one had always supposed was matter, electrons and protons, and what we do suppose is matter, were also wave phenomena and special kinds of waves, stationary waves, corresponding to the stationary states and time-changing waves corresponding to the flow from one stationary state to another. Actually, these waves are abstract and they are not like water waves where you just see matter going up and down. They are not like sound waves where the density of air varies periodically in time. They are not like electromagnetic waves, radio waves, where you have electric fields that change periodically with time. They are a wave of an essentially new kind and they also describe what happens when you are dealing with very weak light, where its corpuscular properties and its wave properties both are manifest. In very strong light you have so many particles that the fact that they are particles at all plays no detectable part. But this is an order, more abstract this way, and it represents the state of our information obtained, either directly or indirectly, from experiment about a system, about the electron in the hydrogen atom, about the light wave, about much more complicated things, and represents and contains in it the future evolution of the system from what we learned about it, its state when we last looked at it. From these waves, picking the right ones to correspond to what we learned and knowing how they change with time, we make predictions about the future of atomic systems and with a fantastic degree of accuracy and with an astonishing range and scope about just what the atoms in an exploding bomb will do, about just what the atoms inside a star do, about why certain substances and only certain substances are superfluid, that is, have no resistence to flow, and certain substances are superconducting, have no resistance to electric current, all kinds of magic things and the periodic system and a lot of chemistry until it gets easier to study it in the laboratory. These statistical descriptions are carried by the nature of the wave and the wave represents information. The finiteness of the light quantum and the energy of an individual particle of light, these discreet states in the atom represent a total, a wholistic trait in the sense that it is quite missing in large scale physics, in the sense that apart from an attempt, a successful attempt, to get information about the object, the atom or light or whatever it is, we have no grounds for making predictions at all. Once we have made the experiment which means making a physical connection between the object and some way of studying it designed to get this information, once we have done that, until the next time we look to get some other information, this whole course takes place as an individual and indivisible development. And it's not, in general, completely reproducible. If the first piece of information is the same, the second one doesn't have to be the same. This is what we mean by saying chance. There is chance built into such a system. Now you might say, why don't I look and find out. The point is, if you look you lose the information you already had because you cannot look with infinite gentleness. The fact that light is corpuscular, the fact that the waves of matter are discreet, means that all transactions, whether taking place between atomic systems, unobserved, or taking place between atomic systems and a machine for observing them, are finite and course-grained and wholistic, that cannot be made infinitely gentle. I can choose what kind of information, what kind of observation. I can't try something else without losing the validity of what I found out first. I can get a new answer and predict on the basis of that but I can't keep the old because in all of these dealings between atomic objects, the equipment, there is this all or nothing character to which I refer. The same discreet, wholistic character of light quantum in atomic states characterizes every transaction in which we get any knowledge at all about the system. There is, of course, the possibility of not getting any knowledge but then there is also the possibility of saying any prediction whatever and you have lost any chance of describing what is going to take place. And it is, of course, this which brings in the inherent chance, if you are limited in what you can study, because it continues the study to round it out, you lose what you had before. Then you would not expect to be able to make the kind of prediction which we can do on large scale things rather well because we can find out all about them without worrying in any way about uncontrollable, indescribable changes that occur by virtue of our very attempt to acquire information. This is not a chance or probability that has any direct connection with what we meet in ordinary life, or what one meets in classical, statistical mechanics. If you do try to say'well, I'll measure something, I'll find out where the electron is pretty accurately and then I'll suppose it has some velocity and then I'll predict where it will be later and I'll average over the different velocities' then you get a wrong answer. If you know where it is, you make a logical error in supposing that it has any velocity, any specific velocity. You must allow for the fact that this is essentially an incoherent and indeterminate thing. This is the Uncertainty Principle which says that there are limits on the precision with which different physical measurements can be carried out on an atomic system, limits which make no difference when we are talking about large objects which are decisive in atomic mechanics. It is the root of what Bohr called 'Complimentarity', this relation, or complimentarity, between the various aspects of the system which are accessible to observation which in toto are needed to complete the arsenal of a system but between which we could choose in an experiment and for which we must make the right choice for an experiment designed to suit a given purpose, but which can't be compatibly done at the same time in the same situation. This general philosophical notion, actually, Bohr had in him in his reflections on culture and on morality, long, I think, before the beautiful example came along in the heart of physics. But the point, you see, is this. Until the act to acquire some connection between what we're studying and us, through other matter, meters or gauges, until we perform an experiment, there isn't anything there at all. You can't say what state it's in, what it will do, you cannot say, it has some objective configuration, but I haven't bothered to find it out, because if you give it this objective configuration, then you can suppose that it is one thing or another. You can say, I will make some sensible average over the possible configuration and then I'll know the probable results. And this has nothing to do with the world of nature. It is necessary to say that only by the act of enquiry do you obtain that objective account of the thing you're looking for, on which you can base prediction, and which you can tell your brother physicists about. This of course does not mean that because there is an element of indeterminacy on an atomic scale, this has anything to do with the all-pervasive and inherent sense of freedom and responsibility which we have when we have to make up our minds and speak and act. This is almost a meaningless way of putting it and I would be willing to say it was a meaningless one. Yet one has a relative parable because if it is true that in so simple a thing as physics, and this is simple physics, although not familiar, knowledge is inherently incomplete, the different situations exclude each other and yet that a rounded description even of the simplest of physics would be sacrificed if one kept only one way of going about it, only one out of the multiplicity, then it does seem again most reasonable to think that very similar things will be general features of the human experience in which the very first elements of perception and incognition involve choice and involve laws. Then it would be a very natural thing to say that however the line is drawn between judging things in terms of understanding them, its necessary consequences, as following from the laws of nature and judging things as expressions, of good or of evil, of human purpose or other purpose, this whole world is involved with judgment of the appropriateness of the terminology and the ideas in a concrete situation. It is the restoration, of a sense, of health in our public, common life. I don't mean of governmental life but our common life, as to how such lines are to be drawn. It is one of the great needs of our times, one of our great needs. This restoration will, of course, not come by the study of science. It will be done better if it is opened to the full flood of every kind of valid knowledge that has come up in the sciences. It will not be drawn by this knowledge but it will be guided by it and illuminated by it. I have to admit that I had a great deal more to say but I will work it in on Thursday.

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