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My Test-Tube Trials

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Though planned experimenting, as is done in our laboratories today, under controlled and reproduceable conditions, is of fairly recent growth, experimenting as such must be very old indeed, nearly as old as man. The oldest recorded experiment is the eating of the forbidden fruit, and one can see in it the touch of viciousness that has characterized some of the applications of science all through the centuries. But in spite of these misuses, the influence of science, on the whole, has been beneficial. However that may be, one thing is clear, namely that science has come to stay, and the ~~ultimate~~ responsibility for ensuring its proper growth, and also for safeguarding against possible misuses, rests, as in other matters, ultimately with ~~on~~ the people.

¶ The growing popular interest in science, particularly noticeable during recent years, is therefore a healthy sign; and I am glad to ~~being~~ able to participate in this series of talks, ~~as~~ which evidently is intended to foster this interest.

Looking back on my scientific career, the five years that I spent in the laboratories of the Indian Association for the Cultivation of Science as the Research Associate of Professor Raman, collaborating with him in the series of investigations on light scattering that led to the discovery of the Raman effect, stand out in my memory as the most exciting period. It has frequently been said that each ~~piece~~ ~~of~~ scientific research has a ~~distinct~~ personality (of its own.) There are, however, certain broad features, ~~certain~~ ~~patterns~~, in the methods of attack, ~~or~~ in the unfolding of the subject, or in the final solution, that suggest ~~strong~~ resemblances between some of them. ~~researches~~ ~~though they may be in different fields~~. The researches that led to the discovery of the Raman effect, to my mind, suggest some such resemblances ~~with~~ to three well-known earlier investigations.

Nearly a century ago the great mathematician Gauss made a systematic analysis of the magnetic field of ~~the~~ earth observed at various stations on the earth's surface ~~of the earth~~. From such an analysis he was led to the conclusion that the major part of the magnetic field observed — nearly 96% — should be attributed to causes inside the earth, and the remaining 4% to causes outside the earth's surface ~~of the earth~~. Looking for probable causes outside, he was forced to postulate the existence of an electrically conducting layer in the upper regions of the earth's atmosphere — and this in spite of the fact that the then known properties of the ~~air~~ (did not permit) ~~did rendered~~ the existence of such a conducting layer ~~highly improbable~~ in the atmosphere. ~~As we know now,~~ Gauss's postulate has since been amply verified. It is ~~indeed~~ that propagation of wireless waves over large distances on the surface of the earth is (at all) ~~rendered~~ possible, ~~just it is~~ ~~because of~~ because of the existence of such ~~a~~ conducting layers ~~of the~~ ~~in the upper regions of the atmosphere~~ ~~type postulated by Gauss~~.

The second of the researches I referred to is that of ~~to~~ the late Lord Rayleigh, who, from a systematic study of the small but persistent difference between the density of nitrogen isolated from the atmosphere, and of nitrogen prepared chemically in the laboratory was led to the discovery of argon. As many of ~~all~~ you know this was soon followed by the discovery by Ramsay and others, of the other rare gases. At the ~~s~~ time the discovery was made, ~~though~~ it was ~~known~~ inferred from the few vacant places left in the Periodic Table of elements that there were yet some elements to be discovered belonging to these vacant places, and having properties predictable in a general way. But the existence of a whole group of elements, of the ~~type~~ kind discovered by Rayleigh and Ramsay, claiming a separate (and almost privileged) column, ~~and in a sort of privileged place~~ in the Periodic Table, and having very special properties, had not been suspected at all.

The third of the researches that I referred to ~~[illegible]~~ is that of Compton, who, following up the clue offered by the observed softening of X-rays ~~[illegible]~~ ~~[illegible]~~ when ~~being~~ they are scattered, ~~especially~~ ~~particularly~~ particularly by light elements, was led to the discovery of ~~the~~ a finite change of wave-length in the process, which could ~~the~~ normally be explained only on the basis that ~~the~~ X-rays in their ~~collisions~~ interactions with the electrons of the ~~scattered~~ scattering medium behaved like particles, rather than like the waves which the known optical properties of X-rays had indicated them to be. ~~As many of [illegible] [illegible] [illegible]~~ The

~~The~~ The Compton effect thus proved ~~thus~~ to be one of the strongest supports for the quantum theory. ~~of X-rays and of light~~.

In all the three researches that I referred to, we find a certain residual effect investigated systematically, leading ~~inevitably~~ irresistibly to ~~conclu~~ ~~result~~ conclusions ~~which~~ that are ~~quite~~ ~~novel and~~ quite unexpected, and ultimately to a new phenomenon.

In the experiments on light scattering also it was found in the very early stages of the investigations that a small part of the scattering was of a different colour from the incident light. On isolating this part of the scattering from the rest, and examining it, it was found to be strongly polarized, even under conditions ~~under~~ which all known types of secondary radiation would be quite unpolarized — thus indicating that an entirely new type of scattering was involved. A spectroscopic examination revealed its true nature, and thus led to the discovery of the Raman effect. Here again, as in the parallel researches that I mentioned, on the basis of the then available knowledge, one would hardly have expected such an effect, ~~particularly with the vibrational energies of the~~ ~~in phenomena~~ ~~molecules, which are the ones actually involved~~, and least so in liquid media, in which the effect was ~~actually~~ first observed.

There is a saying attributed to Lord Rutherford that a young researcher ~~has~~ needs to be suggested only one research problem. The ~~obvious~~ implication is that one problem well investigated leads on to another, and to yet another, and the number grows so rapidly that the difficulty for the researcher is not one of finding a suitable problem, but of choosing from among the numerous ~~one~~ problems that ~~must~~ have cropped up in the course of his own earlier investigations. Mine has been no exception to this general experience. Though my researches have extended over a fair range of subjects, there is ~~naturally~~ a connecting thread ~~link~~ which can be traced through most of them, if they are taken in their natural sequence.

Next in importance to the studies on light scattering come the extensive investigations made by me in collaboration with some of my colleagues on the magnetic properties of crystals. As is well known many of the salts of the iron group, and the rare ~~earths~~ earths group, of elements are magnetic. This indicates that the metal ions in the crystals of these salts behave like elementary magnets, ~~and~~ and are capable of turning round ~~inside the~~ and taking up definite orientations when placed in a magnetic field. Such a rotation of the elementary magnets, since it ~~but~~ occurs inside a solid, cannot be completely free, but will be ~~greatly~~ to some extent restricted. The most interesting feature about these restrictions on the freedom of rotation of the elementary magnets is that they arise from the strong <u>electric</u> fields ~~that~~ ~~occur~~ in their neighbourhood ~~of these elementary~~ ~~magnets~~ and not from any magnetic fields. Hence these magnetic studies supply a good deal of information regarding these electric fields their intensities, their symmetries and other features connected with the binding of the elementary magnets with their neighbours — information of a kind ~~which is~~ that is not easily accessible otherwise. ~~As one exa~~

As an example of this usefulness of

this information I may mention that it is precisely these binding forces that determine how close to the absolute zero of temperature one can reach by the magnetic cooling method with a suitably selected magnetic substance.

The benzene ring with its peculiar plane hexagonal structure, and some of its electrons moving freely from atom to atom over the whole of the ring (just like the conducting electrons in a metal) has many striking properties. With several such rings condensed together so as to form a compact hexagonal net work the extent of migrations of these mobile electrons increases correspondingly, and such of the properties as are influenced by these electrons become increasingly striking. Indeed in the crystal of graphite each layer of the flake is one such net work of carbon atoms, extending almost indefinitely in all directions in the plane. It becomes of great interest to correlate the remarkable optical, electric and magnetic and other properties of graphite with such a structure. These and similar problems connected with the benzene ring have formed the subject-matter of numerous investigations carried out in our laboratories.

Finally as a striking illustration of how different branches of Physics help one another to develop, how ideas which have proved fruitful in one branch of physics may, with advantage, be transplanted to other fields, if conditions are suitable, I wish to mention some recent investigations in our laboratory on the electrical properties of metals and alloys. As you all know the blue of the sky arises from the scattering of sunlight by the atmosphere. If the atmosphere were perfectly homogeneous, there would be no scattering at all, and the sky would be pitch dark. But actually due to the constant microscopic thermal agitations that occur in the atmosphere, there are local fluctuations in density which produce the inhomogeneities that are needed to account for the observed scattering. The deep blue of the sea is also explained in the same manner.

Applying the ideas to metal, and regarding the passage of electric current through the metal as equivalent to propagation of electron waves, one may, not only qualitatively but also quantitatively, regard the electrical resistance of the metal as due to the scattering of these electron waves; here again the scattering arising from the local thermal fluctuations in the density of the medium. Now, the higher the temperature the more violent will be ~~the~~ the fluctuations ~~will be the more violent the higher the temperature, and the well known~~ and the larger will be the resistence, which is ~~as is~~ actually ~~observed~~. the case.

~~Now~~ If, on the other hand, we take a mixture of two liquids, then in addition to the ~~the~~ local fluctuations in density, there will also be local fluctuations in the ~~relative~~ concentration, due to thermal agitation, and a correspondingly increased scattering. ~~Also~~ Taking a mixture of two liquids like carbon bisulphide and methyl alcohol, there is a critical temperature above which they mix freely, but below which they separate out into two ~~separate~~ layers. Now in the neighbourhood of this temperature, the fluctuation in concentration ~~may~~ will naturally be enormous, and the corresponding scattering much greater than the ~~as~~ density part of the scattering.

In some of the ~~b~~ alloys we get a ~~t~~ similar phenomenon. At low temperatures the atoms of ~~the each of~~ the component metals occupy each their allotted positions in the lattice. ~~But~~ But as the temperature is raised, ~~then~~ some of the atoms tend to occupy wrong positions, until finally, when we reach a certain critical temperature, ~~the~~ the atoms of ~~the~~ the two kinds occupy the lattice positions quite indiscriminately, i.e. quite at random. The ~~enormous~~ abnormal ~~increased~~ ~~ris~~ electrical resistance of these binary alloys observed in the neighbourhood of ~~the~~ the critical temperature receives a ~~natual ex~~ natural, and quantitative explanation ~~as~~ as due to the enormous increased fluctuation in concentration, and the corresponding increase of the scattering of the electron waves.