FUEL RESEARCH INSTITUTE
JEALGORA, P.O.
MANBHUM, BIHAR

D.O.No. Est(1)/47/1813 Dated, March 16th 1951.

Personal

Dear Dr. Krishnan,

Herewith a draft notes of the lecture you were kind enough to give here on Graphite a few months ago.

I must apologise for the delay. Would you be good enough to read, mark, and gallantly correct the script and enlarge or modify according to the taste of the lecturer? (S. Weller).

I did not go to Poona last week although I think I ought to have been present as the issues were fundamental, and fuel is fundamental.

McBain has asked me to go also for the next meeting on April the 6th. Does the T.A. involved make the Council furiously to think?

With kind regards,

Yours sincerely,

J. Whitaker

Dr.K.S.Krishnan,
Director,
National Physical Laboratory,
Hillside Road, New Delhi.

Enclo:

Dr. Whitaker, Ladies and Gentlemen,

I appreciate the honour of being invited to give the first Foundation Lecture of a sister laboratory of ours. I do not think it is necessary to reply in detail to the kind things that Dr. Whitaker said. If I had a pigment like his I should blush. I shall just thank him for his kind words, ~~he expressed~~.

The subject I have chosen for to-day's lecture is "Structure and Properties of Graphite". Graphite is not only the distant sister, as Dr. Whitaker mentioned, but probably very much closer to coal, though I personally prefer to keep away from it because all that I know is only about graphite. I shall try to elucidate the structural properties of graphite and then leave it to him to make a closer approach if he wishes to.

You know carbon is unique among the elements in various ways and it is apparently due to its peculiar position in the pericdic table. It has, in addition to two electrons (K shell) which are closely bound to the nucleus, four outside electrons ($2S_2$, $2P_2$) which would normally be distinguished by a physicist as two having an angular momentum zero and the other two one. But whenever the carbon atom enters into combination with other elements the four outside electrons are hybridised and behave in an identical manner. To find out the nature of the binding force we have got to take into account the condition which would correspond to the stable minimum energy state. There are two alternative ways of doing this. One of them corresponds to all the four electrons being identical and being directed towards the corners as in the case of a tetrahedron. The other alternative is that three electrons are in plane directed towards the corners of an equilateral triangle from the centre making with each an angle of 120° and the fourth one is perpendicular to the plane. This fourth electron is called a pi-electron to distinguish it from others and it has interesting properties. Taking as an example the well-known benzene ring we can see that three of the electrons are easily accounted for, while the fourth electron is not. Much of the work of the organic chemists in the past were concerned in locating the position or the direction of this electron. You have the famous

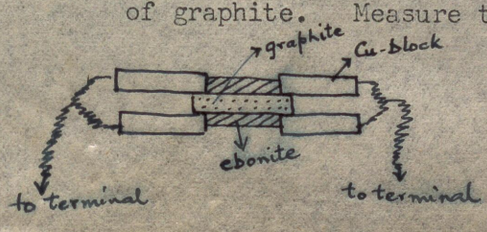
Kekule model, Armstrong model etc. of benzene ring. All these models merely show that there is something very deep which the organic chemists could not solve from purely chemical data which were available. The eseence of the solution from quantum mechanics is that the odd electron which they were trying to locate is not localised at all. It is a vagabond electron and it can move anywhere in the ring. Now you may ask how and why does the electron move?

One of the greatest triumphs of modern physics is the reconciliation of wave mechanics with particle physics. You know nature has a curious way of hiding her truth. All the physical quantities in nature can be compared in a peculiar way so that any attempt, even by the most accurate experiment, to get complete information about both position and momentum.with the same accuracy becomes impossible. When accuracy of one component is achieved, all chance of getting accurate information about the other becomes nil. It is not just due to an accident which occurs in any single experiment but it is right through. Imperfection is the essence of all physical qualities. Energy and time are two conjugate quantities and both cannot be measured at the same time with the same accuracy. When we measure the position, we are uncertain about its momentum, its energy. We may be able to say with what velocity a particle is moving provided you do not ask for its position at the moment. This inability has nothing to do with human imperfection of measurement. Thus an uncertainty exists about the result of an experiment to determine the conjugates time and energy at any particular moment. In other words, a certain indeterminancy is necessarily associated with all measurements of atomic magnitudes. This is similar to the example of a schoolboy who knew all the dates in history of but did not know what happened on those days.. The uncertainty has nothing to do with human imperfections or defect in the instruments. One of the conjugates i.e. energy, is associated with wave property and the other i.e. time, is associated with particle property. So when we localise an electron, i.e., its position, we do not know what energy it possesses. When we measure the energy, it may actually be greater. By allowing the electron to go round the

nucleus of the benzene ring we give it much more freedom to move. The wave-length associated with the electron will be greater, the greater the distance over which it can move. We may consider the existence of alternate single and double bonds in a benzene nucleus and we can ultimately come to the conclusion that in benzene, the hydrogen atoms have been pushed into the periphery. The structure of graphite consists of hexagonal layers of molecules, each layer being the condensation of an infinite number of benzene rings in which the hydrogen atom has been pushed out of the periphery. This was all that was known of the structure of graphite until two years back when X-ray and electron diffraction measurements showed it to be otherwise. .. .. .. (Details reqd.)

There can be three types of arrangements. It is curious that even the single crystals in certain proportions are of the type A B C and the remainder of the type A B. The proportion is more or less the same in most of the graphite. About 14% of graphite is ABC repetition and the rest 86% AB repetition. This imperfection in crystal is apparently governed by some law which we do not understand at present. The distance between 2 layers is found to be 3.4 Å and the carbon-carbon interatomic distance 1.4 Å. This means that in the plane the atoms are bound to one another far more tightly than between the layers. The pi-electrons , however, can travel all over the plane freely but it cannot leave the plane and jump to the next one as the energy of binding in the plane is larger. So in the planar direction graphite is as good a conductor as metals, the electron conducting electricity, but in the perpendicular direction it is as good an insulator as any non-conductor. This you can confirm by merely taking a layer of graphite and putting it between two blocks of brass and measuring the resistance. The resistance in the perpendicular direction is at least a thousand times the resistance in the planar direction.

There is another property and I would like to mention an observation which would interest those who have tried experiments of this type. Take two copper blocks and between the two place a layer of graphite. Measure the resistance. Then go on reducing the thickness of the graphite by scraping off, measuring the resistance at each stage, until the thickness



is about 1/10 mm. It will be noticed that instead of the specific resistance only remaining constant, the absolute-resistance also remains almost constant till a very low thickness is reached. Whether you use a thick or thin plate of the material, the resistance remains the same. Normally in a conductor, conductivity increases with length. But here the resistance gives quite divergent value .. .. (further details & explanation reqd.)

There is one other interesting property associated with the majority of these electrons. Measurement of magnetic susceptibilities along directions in the basal plane gives a value of about -0.5×10^{-6} e.m.u. per gram, which is nearly that of diamond; the susceptibidity along the normal to the plane is, however, more than ~~normal to the plane~~ forty times greater being equal to -21×10^{-6} or -22×10^{-6} per gm at room temperature. Measurement of the susceptibility of a single crystal of graphite under high pressure was carried out by Bridgeman by keeping the magnetic field constant and rotating the crystal. The abnormal values of susceptibility observed in the direction normal to the basal plane are quite significant.. .. .. .. (details reqd.) Dr. Bridgeman's measurements were widely different from mine. These observations also raise many other points of interest to theoretical phhyscists who are concerned with the quantum mechanical consideration of these mobile electrons. These mobile electrons extend over the infinite planes in graphite. The Russian physicist Landorf has applied Fermi's statistics to diamagnetic substances and has found that susceptibility varies with temperature and degeneracy sets in at 600°C, Making use of the relation $\chi = -\frac{n\mu^2}{RT}$ the values of χ were calculated, but these correspond to one atom; ~~but~~ by extrapolation other values can be found.

Refractivity (Details required)

Poly-benzene nucleus - introduction of impurities e.g. benzene with naphthalene etc .. ..

Boron nitride has the same structure as graphite.

Swelling of graphite (Details required)

It is due to other ions getting sandwitched between layers

.. ..

AO May kindly examine and advise, so that a suitable reply can be sent to Dr Whitaker

7 JAN 1954

FUEL RESEARCH INSTITUTE
JEALGORA P.O.
MANBHUM, BIHAR

No E-447/53/16042

December 28, 1953.

31 DEC 1953

Dear Dr. Krishnan,

I enclose an application from one of my IIIrd. Division Clerks, Mr. I.D. Sharma, requesting for transfer to Delhi. Mr. Sharma is a resident of Delhi, and naturally he desires to live within his family there. He has been suffering from financial difficulties since he came here. Could you help him in absorbing him in your Laboratory as and when a vacancy arises?

With kind regards,

Yours sincerely,

J. Whittaker
Director

Enclo:

Dr. K. S. Krishnan,
Director,
National Physical Laboratory,
Delhi.

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH

NEW DELHI 26.6.1958

My dear Krishnan,

The return of the prodigal, — or the bread cast on waters?

Anyway it is a first class selection — not to be loaned lightly, if I may say so. Practically a literary education in itself.

Again many thanks

Yours sincerely

J. W. Whitaker

FUEL RESEARCH INSTITUTE
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MANBHUM, BIHAR

10.2.55.

My dear Krishnan,

This is a note to thank you for the Chiena tea which is the best I have ever come across. My wife, alas, has never acquired the taste — & you may have been surprised that at Delhi I regarded the offer as a personal gift rather than a joint one. Even after ~~trying~~ this marvellous blend & flavour, she retains her preference for the tea of India, & charges me with communistic leanings of the Chinese variety & not of the Russian! [cf. caviare, I say] But for those who like the subtlety of taste of our Eastern brothers beyond Tibet, the tea is really 'first class first', as they say in the Indian Universities, and I wish again to thank you for it. Finally, I can assure you that it ed. no[t] [illegible] Spirit of Will Shakespeare's "second class bed" bequest to Anne Hathaway, or for any ulterior motive.

With all good wishes, Yours sincerely, J. W. Whittaker

(J. W. W.)

P.S. And now to business:-

Can you tell me where I can find out how to allow (precisely & mathematically) for the modification in density or in spec. volume which takes place in kaolin and pyrites? Calculated from atomic volumes, the densities are not those which are usd. expect unless we make the allowances for the spacing between the atoms, you will recall.

JWW