Prof. C.V. Raman's lecture delivered on December 22, 1968 on the Foundation Stone-laying ceremony of the Community Science Center, Ahmedabad.

WHY THE SKY IS BLUE?

When I was asked to choose a scientific subject for my lecture I had no difficulty at all in choosing the subject of "Why the sky is blue." Fortunately, nature has been kind today; as I look up and see, the sky is blue: not everywhere, as there are many clouds. I chose this subject for the simple reason that this is an example of something you do not have to go to the laboratory to see. Just look up look at the sky. And I think it is also an example of the spirit of science. You learn science by keeping your eyes and ears open and looking around at this world. The real inspiration of science, at least to me, has been essentially the love of nature. Really, in this world, wherever we see, we see all kind of miracles happening in nature. To me, everything I see is something incredible something absolutely incredible. We take it all for granted. But I think the essence of the scientific spirit is to look behind and beyond and to realize what a wonderful world it is that we live in. And everything that we see presents to us not a subject for curiosity, but a challenge, a challenge to the spirit of man to try to understand something of this vast mystery that surrounds us.

Science continually attempts to meet this challenge to the spirit of man. And the great problem today, which Dr. Sarabhai has addressed himself to, is how to rouse the younger generation of our country to meet this great challenge before us, once again to build up India into a great center of knowledge and learning and endeavor. Well, I wish you all success. Now let me turn back to my problem "Why the sky is blue?"

I raised this question because it is an easy subject. I only have to look up and see that the sky is blue. But why is it blue?

The interesting point is that it is easy to answer that question in a casual way. If you ask a Botanist, why are leaves green? He murmurs, 'Chlorophyll'. Finished. You see all scientific questions can be disposed of in that summary fashion, in one or two words. You can surely pass your examinations with that kind of answer, but that is not the real answer. As I said before, the scientific challenge of nature is to think not only to discover but also to think, to think continually and to try to penetrate this mystery: "Why is it blue?" That is a very interesting problem, because two things are there. The sky is there and I am here. I see it is blue. It is the human brain and the human mind as well that are involved in this problem. Now suppose we put this problem before the young people. Don't read any book about it; don't ask your teacher. Let us sit dawn and try to think out this problem: Why is the sky blue? Look at it as if it is a completely new scientific problem about which nobody has troubled himself before. You sit down and think it out and you will find it a most exciting thing to ask yourself that question and see if you can discover the answer for yourself. Now I will put it to you in this way. The best way to answer a question is to ask another. At night, we all see the stars. On a fairly clear night you see the stars twinkling in the sky. Why are the stars not visible in daytime? Please ask yourself this modest question. Well, the reason obviously is that the earth, as a lady, has hidden herself under a veil. The sky is a veil, which she has thrown around us. We cannot see the stars during the day, because the veil hides the stars. And what is this veil? The veil obviously is the atmosphere of the earth. The same veil, which at night is so transparent that we can see the faintest star and the Milky Way, is covered up in daytime. Obviously, it is the atmosphere, which is the veil. And we see the sky as blue only because we have not got other thicker veils like these clouds. You see for example, those clouds high in the blue sky. Obviously therefore, for the sky to be really blue, there must be nothing else, no clouds and perhaps no dust. The clearer the sky is, the bluer it is. So the sky is not always blue; it is sometimes blue and sometimes not blue at all. So that the mere looking at the sky enables us to understand the condition of the atmosphere.

Let me say one thing more. Obviously, the sky and the atmosphere are lit up by the sunlight. Sunlight is passing through this great column of air and obviously it is the atmosphere, something that is transparent and invisible at night, that is seen to us by the light - sunlight - passing through the atmosphere. Now I want you to ask yourself another question. I don't know if any of you have had the curiosity to look at the clear sky on a full-moon night. You know that moonlight is only the sunlight incident on the moon and is diffused or reflected. I don't know if any of you have really watched the sky on a clear full-moon night. You will be astonished to find that the sky is not blue. It appears pale, you just see some light and you see some of the stars even under the full-moon sky, but the sky is not blue. Why is it that the sky, which appears blue in sunlight, does not appear blue in moonlight? The answer obviously is - the illumination is far less powerful. You don't require to be much of a mathematician to calculate the ratio of the intensities of full- moon light and sunlight. I present it to same young mathematician to sit down and work out. How big is the moon? What should be the brightness of moonlight? It is a little astronomical problem. Rough arithmetic would tell you that moonlight is something like half a millionth part as bright as sunlight; you would think it is terribly small. But moonlight, when it is there seems very bright though it is only half a millionth part of the brightness of sunlight. Why does it look so bright? Well, the eyes have got accustomed to much lower levels of illumination. So moonlight appears very bright but not so bright, as to veil all the stars. But the sky, it does not appear blue. So this comparison of sunlight and moonlight brings to our notice a very remarkable fact. It is an absolutely fundamental aspect of human vision that to perceive colour, you must have a high level of illumination. The sky is blue, merely because sunlight is brilliant: moonlight is much less brilliant and so you don't perceive colour. This is a principle, which perhaps is not so widely appreciated as it ought to be. Colour is only perceived at high levels of illumination. The higher the illumination the brighter are the colours. You go down to low levels of illumination, say, a millionth part, half a millionth or a hundred thousandth part of sunlight, the sense of colour disappears. Now this is a very fundamental fact of human vision, which simply comes out of nothing else but just observation and thinking, that's all. I can go on giving any number of illustrations. Perhaps the most striking illustration emerges when you look at the stars or such objects as the Orion nebula through small telescopes. Let me say here and now, my belief that there is no science so grand, so elevating, so intensely interesting as astronomy. It is amazing to see how many people high up have never seen the sky through the telescope. I want to tell them something which is absolutely incredible: Nothing more than a pair of binoculars, a good pair of binoculars is needed to educate oneself in the facts of astronomy I think a man who does not look at the sky even through that modest equipment - a pair of binoculars - cannot be called an educated person, because he has missed the most wonderful thing and that is the universe in which he lives. You must have a look at it. You don't see much of it, but you see a little and even this little is enough to elevate the human soul and make us realize what a wonderful thing this world is.

I come back now to the problem of the blue sky. I want to pose to you a very difficult question. Why is it that we perceive the blue colour only under intense illumination in sunlight, and not in moonlight? I will bypass that and come back to the question: Why is the sky blue? Well, we all know that white light is composed of all the colours in the spectrum. You divide white light into various colours; you start with deep red at one end, light red, orange, yellow, green, blue and violet, so on, the whole range of colours. When I look up at the sky, I see only the blue; what has happened to the rest of the spectrum? This is the basic question. The question becomes a very pressing one when I remark that when we actually spread out sunlight into a spectrum, the blue part of it is the least intense part. Less than 1/40th of the whole energy of the brightness of the sunlight appears in the blue of the spectrum and we see only that $1/40^{th}$ part. You don't see the rest of the spectrum. It has simply vanished. It is not there at all. You can look very very hard and try to see if you can see any red or yellow or green in blue sky. We don't see it. The blue has just masked the rest of the spectrum. This is a very remarkable fact. If you watch the sky on some occasions, you get great masses of white clouds, what they call the cumulus clouds not huge things, just little bunches. It is a beautiful sight to see the blue sky and these little masses soaring above. I have derived great satisfaction in just doing nothing at all and looking at these masses of clouds and the blue sky. The interesting point is precisely when you have the clouds moving about that the sky is bluest. What it means is that these cumulus clouds in the course of their formation just cleaned up the rest of the atmosphere. They take up the dust particles and concentrate them on the white clouds. The rest is left nice and clean. You see the beautiful blue view against the brilliant white; it is a very lovely sight. A sight for the Gods; only you don't bother to look at it because it is so common. You may ask me, how is the cleaning process accomplished? Now here is a wonderful story. When I ask the young people, "What is the cloud?" “Oh! Sir, it is steam". The usual answer you get is that the cloud is steam, but it is nothing of the sort. The cloud consists of particles and what looks to us, as great masses of white clouds are just droplets of water. Water is heavy but why does it not fall down? We find it floating in the air! You see that is another problem. Already I am going from one problem to another. We ask ourselves, what is a cloud? Why is it floating in the air? The moment you ask the question, "Why the sky is blue?" you go deeper and deeper into some of the deepest problems of Physics. Now the interesting point is this you cannot have a cloud unless you have dust particles about which it can form.

There must be particles of some sort, may be very small, maybe very large. They call it in learned language 'Nuclei'. If there is no dust in the air, there will be no cloud and no rain. You see how from the blue sky, we have got on to the origin of rain, rainfall and so on. One thing leads to another. That is the essence of science. You must go deeper where it leads you. You cannot go thus far and no further. The moment you raise a question, another question arises, then another question, so on and so on. Ultimately, you find that you have to travel the whole field of science before you get the answer to the question: Why the sky is blue? So I told you this fact about the clouds.

Well, I should say the clouds clean up the atmosphere. Clouds form and then leave the atmosphere clean, comparatively free from dust particles and other nuclei and that is why the sky is blue. So we came down at last to getting some kind of answer to the problem. The sky is blue because the atmosphere is clean and free from dust and all nuclei. The clearer it is, the bluer it looks, provided there is enough light. So you come somewhere near the answer to the question. What is it you are able to see? The fact is that when we see a blue sky, we see the atmosphere of the earth, the gases of the atmosphere, they diffuse the light and we see the blue light of the sky. But still we are far from the answer.

I told you that blue is only 1/40th part of the sunlight. What happens to the rest of the light, the sunlight? That is the question. Now this question can be answered in the following fashion. You look at the white cloud and look at the blue sky. You can compare them with the help of a pocket spectroscope and you find strangely enough that you have to look very-very carefully before you find any difference in the spectrum of the blue sky and the spectrum of the white cloud. White cloud is certainly very much brighter. But so far as the spectrum is concerned, you see in the blue sky and in the cloud the same spectrum. It also starts with the red end and goes on till the blue. But in one case you see the blue, in the other case you see the white. And with great trouble, you look very carefully; you see that there is some difference in the relative brightness. You can see the yellow and the red, not so bright relatively. Mind you, it is a mental calculation. You see the relation of brightness between the blue part of the sky, the blue part of the spectrum and the violet part and the rest of the spectrum. Relatively to the red, the yellow and the green, the blue and violet are stronger in the scattered light in the diffused light of the blue sky. Still you are very far from the answer. It does not explain why don't we see the rest of the spectrum. Actually in the blue sky the green and the yellow and the red are still there, they are still far brighter, perhaps not so perhaps not 40 limes but perhaps ten times brighter than the blue. Then why do we see the blue and why don't we see the rest? Here again you come across an extremely difficult question to answer. The actual brightness of the blue part of the spectrum in skylight is still much smaller than the brightness of the rest of the spectrum but we don't perceive that part of the spectrum. Now this is very simple and very surprising. But there is a nice little experiment which, perhaps one day, will be shown at the Science Center which will enable you to see at least that it is not an exceptional phenomenon. It is one of the most fundamental facts of human vision that the blue part of the spectrum inspite of its weakness dominates the spectrum in certain conditions and plays a role tremendously far more important that its actual brightness warrants. Now the experiment is the following it is a very easy experiment. You take water and put a little copper sulphate in it and then put excess ammonia in it. You will get a solution called cuprammonium. It is very strong it will transmit only deep violet light. Put it in a cell. You go on adding water in the cell and look at the colour of the bright lamp and see that the following thing happens. The deep violet changes into blue. The blue changes to a lighter blue and so on. But till the very last, it remains blue. In the spectrum of the light the solution is transmitting red light, green light, not of course yellow. Lot of light comes through the spectrum and the blue is still only a minor part of the whole. Whatever light comes through the spectrum you cannot see and you cannot even imagine any other colour coming through. And the reason for it is as follows. If you examine the transmitted light through a spectroscope you will find that the yellow part of the spectrum is diminished by the influence of cuprammonium. It absorbs and cuts out the small part of the width of the spectrum, but a very important part and that very important part is the yellow of the spectrum.

Never mind how it absorbs the yellow part and controls the colour. The light is blue simply because the yellow is absorbed and the blue comes into vision. If you take the whole spectrum and if you reduce the strength of the yellow part of the spectrum, at once you find the blue part of the spectrum and the blue colour dominates. This is again a fact of physiology. If you want any colour whatsoever to be showy, you must take out the yellow. Take for example that red carpet which has been spread in my honor, I suppose. You look at it through a spectroscope. I can tell you beforehand, there will be no yellow in it at all. To get any colour, red, green or blue, you must take out the yellow.
Yellow is the deadly enemy of colour. All other colours I mean. Look at the green leaf. All the leaves are green, not because of the presence of chlorophyll - the chlorophyll has a strong absorption of red no doubt. But the real factor, which makes the color green, is the fact that the yellow is taken off chlorophyll has enough absorption of the yellow to reduce the strength of yellow. Well, I examined silks for this. Bangalore is a great place for silk manufacture. I managed to purchase about 25-30 blouse pieces. I got them to verify the proposition that all brilliant colours require the suppression of the yellow region of the spectrum.

Look at the rice field. It is wonderful. Look at the rice field with a spectroscope. It looks very much like the spectrum of the blue sky. But the only visible difference you can actually see at a glance between the blue sky and the green rice field is that the blue part of the spectrum has been cut off and that is produced by the so-called carotenoid pigments that are present here, which cut off the blue; the rest of the spectrum looks almost alike. But if you look very carefully, you will see that in the colour of the rice field, you do not get the yellow. The removal of yellow is essential, before you can perceive the leaves as green. You see always this predominance of the yellow. On the contrary, if the yellow is taken off, the blue dominates. If you don't take off the yellow, the yellow dominates. The two are contradictory and they are enemies to each other. The fact is that you can divide -- the physical explanation is deeper still - you can divide the whole spectrum into two pelts. The division is just where green the blue ends: that part of the spectrum extending to green, yellow, orange and red amounts only to yellow. The other parts of the spectrum summed up amount to blue. Now if you take off this or reduce this you get the other. This is the real explanation of the blue colour of the sky and is very significant. You reduce -- not that you abolish -- the intensity of the yellow in the spectrum and of course of the green and the red. It is the reduction of the yellow of the spectrum that is to say the predominance of the blue, which is responsible for the blue light of the sky. Well, one can carry further and say that it is the reduction of yellow that is basic. And why is it reduced? So here comes the second part of it. I could have started with that and said, "Why is the sky blue?" “Oh, the scattering of light by the molecules of the atmosphere". I could have dismissed the whole lecture in one sentence. I could have said just as the botanist says "Why is it green?" "Just chlorophyll". I could have said, "Why is the sky blue?" "Scattering of light by the molecules of the atmosphere." One sentence, "Then sir" you would ask me, “why this entire lecturer”. Because, my young friends, I want you to realize that the spirit of science is not finding short and quick answers, the spirit of science is to delve deeper -- and that is what I want to bring home to my audience and deeper. Don't be satisfied with the short and ready quick answers. You must never be content with that: you must look around and think and ask all sorts of questions; look round the problem and search, and search and go on searching. In the course of time you will find some of the truth, but you never reach the end. The end, as I told you, is the human brain, but that is very far away yet. This is the spirit of science. I should give you an illustration of how by pursuing a simple question, I can go on talking to you as if I have just begun, the real subject of my lecture: "Why the sky is blue". "The sky is blue because the illumination of the sky light is due to the scattering of light by the molecules of the atmosphere". Now this is a discovery, which came rather slowly. The person who first stated this explanation was the late Lord Rayleigh.

I think that dreams are the best part of life. It is not the realization, but the anticipation; I am going to make a discovery tomorrow, that makes a man of science work hard, whether he makes the discovery or not. And this is what I want to emphasize once again. Science is essentially and entirely a matter of the human spirit. What does a poet do? What does a painter do? What does a great sculptor do? He takes a block of marble, chips, goes on chipping and chipping. At the end of it, he produces the dream in the marble. We admire it. But, my young friends please remember what a tremendous amount of concentrated effort has gone in to producing that marble piece. It is the hope of realizing something, which will last, forever, which we will admire forever that made him undertake all that work. Essentially, I do not think there is the least difference whatever between the urge that drives a man of science to devote his life to science, to the search for knowledge and the urge that makes workers in other fields devote their lives to achieving something. The greatest thing in life is not the achievement but it is the desire to achieve. It is the effort that we put in, that ultimately is the greatest satisfaction. Effort to achieve something in the hope of getting something; let it come or not come, but it is the effort that makes life worth living and if you don't feel the urge towards the search for knowledge, you can never hope to be a man of science. You can perhaps get a job in some of the departments, get a nice comfortable salary, in which you don't have to do anything except to wait for the monthly cheque: but that is not science. The real business of a scientific man is to try to find something real and to look forward to the acquirement of knowledge.

Having said all this, may I again come back to the blue sky? I have not finished yet. In fact, to tell you the honest truth, I have only just begun my lecture. Why is it that the molecules of the air scatter light? The obvious thing is this, as I told you, the long waves in the spectrum -- I am using the language of wave optics -- the long waves of the red, yellow and the green are scattered less in the diffused light and the rest quite strongly, with the result that the eye perceives this and not that. Now why is that? The answer is very obvious. The molecules of the atmosphere are extremely small in size, incredibly small compared with what is the standard of comparison, the wavelength of light. The same thing you notice, for example, if you look at a big lake. The wind blows on the waves and you have a piece of cork or wood floating on it. You see the wood trembling. Why? Because the size of the wood is comparable with the size of the waves. But suppose you had a big boat going on the lake; I don't know how big the boat can be, but you see that the big boat is not disturbed so much as the small particle. It is the relationship between the size of the disturbance and the size of the particle that determines the effect the waves produce on the particles and vice versa, the effect produced by the particles on the waves. This is the basic principle, which results in the scattering of the shorter waves by preference. You can show that by any number of experiments in the laboratory; for that, you don't require molecules of air. You require just some water and put in it some substance like bit of soap. You can also make the experiment with smoke: particles small enough will scatter the shorter waves by preference. But you don't get the real rich blue colour unless the particles are extremely small. And as I have already indicated, you must have adequate illumination. Unless the illumination is strong enough, the sensation will be just the palest of pale blues. Now I have came from the scattering of blue sky to the study of molecules. And there the subject begins and it goes on. In fact, I started the subject in the year 1901. What I told you was known pretty well except the vision part of which I have spoken about. That is my most recent work, but what I spoke about molecules and so on was all known in 1921. At that time, we thought it was finished. Today, we know that the faculty of vision and the quality of vision play an immense role in the subject.

The subject of my lecture is not the blue of the sky, but as you must have all understood by this time - it is the spirit of science. What is science? And how can we in this country hope to advance science? How can we try to really make ourselves worthy of our ancestors in the past? That is the real topic of my lecture. It is only the peg to hang the subject upon. Well, the story begins there. The question is how does light interacts with molecules and what happens with molecules and what are molecules and so on. Science never stops. It is going on. The more you find, the more appears that you have to find. That is the attraction of science, provided you are not distressed too much by other people getting in front of you. Don't bother about them. The real point is that it is an endless quest and every new discovery opens new paths for discovery. New questions arise, requiring new answers.

But then, I cannot give this lecture without making some reference at least as to how all this I am talking about is united up with meteorology all the time. But the real interest in the subject is not in meteorology at all. The real interest in the subject is the scattering of light, which is the most powerful weapon we have today for understanding the ultimate nature of the molecules of the air. You can count the molecules. You can make the experiment in the laboratory. It is an experiment, which every student of science ought to have seen. You take a glass bottle, a flask and a cork and get all the dust out of it and send a beam of light, it may be sunlight, it may be any thing else but see that the beam of the light goes through the air. You can see the air. The air is not such a transparent, colourless gas; it is not invisible. You can make air visible by means of this scattered light. This is a very simple experiment and ought to be seen by every student of science at least once in his lifetime. You can see air. You can see any gas. You can see any vapour, by the strength of the light diffused by the individual particles. And the more particles you have, the stronger the diffusion. From the strength of the diffusion, you can actually count the number of molecules. I use the word counting, not like one, two, three, four: it is a son of differed type of counting. When I was in the currency office, they used to count the rupees. You know what they did; they did not count the rupees. They counted the bags: they weighed the bags; each bag was supposed to contain 2,000 rupees -- that had to be taken on trust – and then multiply the number of bags and you get a crore (10 million) of rupees. Like that, you count the molecules of the atmosphere. It is only a sort of estimate. But more than that, we can actually see the scattering of light simply by looking through an instrument; you can find out whether a molecule is short or long, whether it is spherical or tetrahedral shape and so on. The study of the blue sky is an immense field of research, an unlimited field of research, which was opened up and is still being pursued.

The quest, you see, is the more the deeper you go. Then the question arises what about light? I cannot possibly enter into all that. Because, my idea, as I told you is just to give you a simple glimpse into how a familiar phenomenon is linked up with deeper problems of Physics and Chemistry. That is the lesson we learn today. From the familiar fact, it is not necessary to hunt round the textbooks to find problems of science. You keep your eyes open and you see that all round you, the whole world bristles with problems to solve; but you must have the wit to solve it; and you must have the strength of mind to keep going at it until you get something. This is the lesson, which I want to bring home to the younger generation in front of me. What is the use of all this? Here again, I want to stress the philosophy of my life. Never to ask what is the use of all this.

As I told you before, it is the striving that is worthwhile. Because we have certain inherent powers given to us to use - observation and thinking -- we must use them. The more we use them, the sharper they become, the more powerful they become and ultimately something will come out of it so that humanity is benefited, science is benefited. Ultimately the aim of scientific knowledge is to benefit human life. And that comes automatically because the problems with which we are concerned in science are always those that lie nearest to hand. They are concerned with things about us. So long as we deal with the problem which arise our of our environment, you never can say that any particular piece of work can be useless. The most important, the most fundamental investigations, though at first might seem an abstraction of nature, are precisely those, which in due course, affect human life and human activities most profoundly. This is a very heartening thing because one should not think that scientific work in order to be valuable should be useful. Scientific work is valuable because it will ultimately prove its value for the whole of human life and human activity. That is the history of modem science. Science has altered the complexion of things around us. And precisely those scientists who have laboured not with the aim of producing this or that, but who have worked with the sole desire to advance knowledge, ultimately prove to be the greatest benefactors of humanity.