Can you see Air?

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"Can you see air?" One immediate reaction to this question is "No, air is transparent". This is a quick and snappy answer that appears to settle the matter, but as we will see, it does not end the story. There's a lot more to be learned by chasing the question where it goes than by just answering it. This question was recently brought up by Navin, a student of Bethany Elementary School in Plano, Texas, USA. He found on the net a reference to a lecture by C V Raman in which is described an experiment to "see" air. Here is a brief passage from the lecture: "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 anything 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 life time." Raman's lecture is inspiring in itself. Although it is titled "Why is the sky blue?", the lecture is really about the spirit of Science. Far from the slot machine style question-answer format that is emphasized by our examination system, the true spirit of Science lies in asking questions and questioning answers, rather than just answering questions!

This article is prompted by Navin's question and our own attempts to answer it. "Can you see air?" Another answer to the question could be "Yes, you are 'seeing air' every time you look up at the blue sky". Light 'bounces off' the atmosphere and reaches our eyes. Blue light bounces better and that is why the sky is blue. This indeed is one of the points made in Raman's lecture. On the Moon, where there is no air, the sky looks black as you can see during a TV broadcast of a Moon landing.

Keywords
Molecules, light, scattering.

We wanted to explore this question afresh. Here is an account of our attempts at seeing air. (Perhaps we should say "striving after wind"!) What does it mean "to see air"?

So now, we see that an equally valid answer to Navin's question is "Yes!". So where does the truth lie? Is air transparent or visible?

Let's ask a slightly different question: Can you devise an experiment to see air in a laboratory? We have all seen air shimmering on a summer's day just above a hot tar road. This effect also appears above a lighted stove. But what we are seeing here is not air but the refractive index changes in it caused by heating. The question remains: Can you devise an experiment to see air?

We wanted to explore this question afresh. Here is an account of our attempts at seeing air. (Perhaps we should say "striving after wind"!) What does it mean "to see air"? Air is composed of many components: gases in molecular form like nitrogen and oxygen as well as dust and pollen. There are particles with a range of sizes from microns to 10 nanometres. Molecules are, of course, too small to see, but they do interact with light and scatter it. Larger particles scatter light more effectively than smaller ones. Let us suppose that we wish to see light bouncing off the gas molecules in air. How would we separate this effect from the light bouncing off dust particles? We found this very difficult and did not finally succeed in seeing the molecular component of air. However in the process, we learned a lot about the interaction of light with matter. We hope that the readers will also benefit from our efforts and be enthused to pursue the matter for themselves.

How would Raman have gone about it?: Our guess is that Raman used sunlight reflected by a mirror into a darkened room. The mirror would be mounted on a Heliostat tracking the Sun. The light entering the darkened room would have been collimated by lenses and passed through a dark chamber with openings for light to enter and leave and a third opening for the eye of the experimenter. After getting used to the dark, the eye is capable of detecting very faint light and we guess this is how it may have been done. Raman would have tried to make a flask or bottle dust free and kept this in the chamber. As you can imagine this experiment would take considerable patience and skill.

Did we see a track in air?: We used laser light in a dark room for our investigation. In the darkened room we noticed after the ambient light was cut out and the eye was used to the dark that there was a clear diffuse track of the beam. There were also bright points of light due to scattering by large dust particles but the track was unmistakable. Is this the effect (not to be confused with 'Raman effect'), that Raman talked about? We would expect the effect to disappear in an evacuated flask. To test this we took a RbNe vapour cell (which was available in the laboratory) at a pressure of 10^{-7} mbar and we allowed green laser light to pass through it. We couldn't see the track at all inside the cell, but we could see it outside the cell. However, this still does not quite rule out the fact that the track outside the RbNe vapour cell could be due to scattering off very fine dust particles which are present in the air but absent inside the cell.

The track was clearly visible if we looked in a direction approximately opposite to the direction of the beam. It was not visible if we looked in the same direction as the beam. This suggests (see below) that the diffuse track may still be due to fine dust particles suspended in air and not due to the molecular component of air. In order to eliminate the effect of dust particles on the scattering one needs to try to see the track in a dust free chamber containing air. We did not know how to do this, so we did a similar check with water.

The track was clearly visible if we looked in a direction approximately opposite to the direction of the beam. It was not visible if we looked in the same direction as the beam. This suggests that the diffuse track may still be due to fine dust particles suspended in air and not due to the molecular component of air.

How we saw a track in water: We took a glass container which we cleaned with methanol and put twice distilled water in it. We noticed that the track was

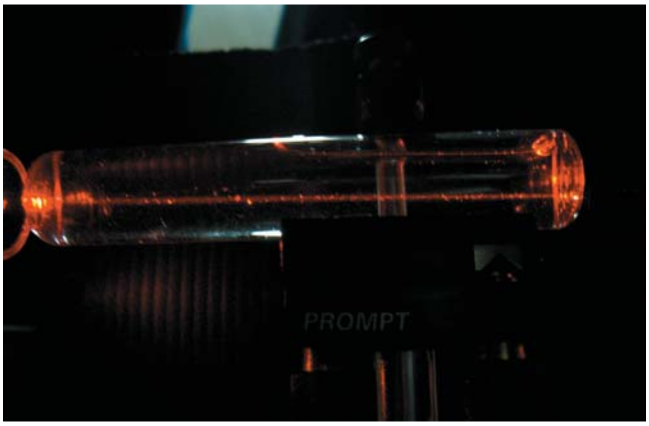

Figure 1. Experimental setup for seeing the track in water using red laser. Notice that the bright spots are due to the use of ordinary water instead of double distilled water.

visible both in the presence of red laser of 10 mW power and green laser of 5 mW power and there were no bright spots in the track indicating the fact that the water was perhaps completely dust free (see *Figure* 1). So the track is probably due to scattering off molecules present in the water and not due to scattering off dust particles present in the water. In contrast to the track in the air which was barely visible if one looked in the same direction as the beam, we found that the track in the water had a scattering profile which was more isotropic, consistent with the angular dependence of Rayleigh scattering. The intensity I of light scattered by a single small particle of diameter d from a beam of unpolarized light of wavelength λ and intensity I_0 is given by:

$$I = I_0 \frac{(1+\cos^2\theta)}{2R^2}\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{n^2-1}{n^2+2}\right)^2\left(\frac{d}{2}\right)^6,$$

where R is the distance to the particle, θ is the scattering angle, n is the refractive index of the particle. This expression is valid in the regime $d/\lambda << 1$. Note that equal intensity is scattered in the forward ($\theta = 0$) and backward ($\theta = \pi$) directions. For larger particles, the above formula does not hold and the scattering is strongly peaked in the forward direction. To sum up, in air we saw scattering strongly peaked in the forward direction and therefore it is most likely due to light scattering off fine dust particles, not the molecular component of air. In contrast, in water we did see a track due to light scattering off water molecules.

Theoretical Estimates: The theoretically calculated mean free path (see [2]) is $L_f = 3\pi N\lambda^4/2(2\pi)^4(n-1)^2$, where N is the number density of molecules, λ is the wavelength of light and n is the refractive index of air. For red light scattering off N_2 molecules L_f is around 180 km, which makes it very unlikely that a simple table top experiment with a path length of metres will render light visible. In contrast, our estimate of the mean free path of scattering for red light off water molecules turned out to be about 1m and therefore a track made by laser light scattered off water molecules is indeed within experimentally observable limits. This is indeed consistent with our observations. One way to increase the effect of scattering in air would be to increase the density, by putting it under pressure or liquefying air. Clearly, this is not the simple table top experiment that we set out to do.

Given that the mean free path is so large, how many photons are scattered out of the beam in a distance of 1m? For a laser of 5 milliwatt power, although the scattered power is only a mere 2.5×10^{-8} Watts, this works out to be 10^{11} photons per second. The eye can get used to low light levels and perceive even a few photons. Was this how Raman "saw air"? Was he able to check that the angular dependence was right? We invite the readers to guess how Raman went about his experiment and what he actually saw.

Statutory Warning: Readers are warned that one should never look at a laser beam (or the Sun) directly since it can damage one's eyes.

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Suggested Reading

[1] C V Raman, Why the sky is blue in *C V Raman - Lectures and Miscellaneous Writings*; http://hdl.handle.net/2289/1509.

[2] J D Jackson, *Classical Electrodynamics*, Wiley, New York, 3rd edition, 1998.

[3] R P Feynman, R B Leighton and M Sands, *The Feynman Lectures on Physics*, Addison-Wesley, Reading, Massachusetts, Vol. I, Ch.32, 1963.