

Classroom



In this section of Resonance, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. “Classroom” is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

! Pressure Melting and Ice Skating

In cold countries, ice skating is a popular sport. The skater is supported on two metal ‘blades’ which move over the ice with amazingly low friction, allowing very rapid and graceful movements (and disastrous falls!). For generations, the text book explanation of this low friction has been the fact that ice melts under pressure (most other substances freeze under pressure). The extract given below, from a recent article by S C Colbeck in *American Journal of Physics* (63 (10): 888 October 1995) tells us that the physics of ice skating is richer, and hence more interesting, than mere pressure induced melting.

“While pressure melting is commonly thought to be the mechanism responsible for the low friction of ice, there are many arguments against it. The high pressures required would cause failure of the ice unless it is well confined by the blade. If the ice and meltwater are confined, just below -20°C liquid water cannot coexist with ice at any pressure because the high-pressure forms of ice appear. If the mechanism does operate, the high pressures would cause high rates of water loss by squeeze in very thin films. Frictional heating by shearing of the water films is much more plausible, as shown quantitatively by the example with equal contributions by the two mechanisms”.

The physics of ice skating is richer, and more interesting, than mere pressure induced melting.



Ravi Divakaran, Department of Chemistry, St. Albert's College, Eranakulam 682018, Kerala.

? Bunsen Burner- Revisited

This is in response to the article titled "On Bunsen Burners, Bacteria and the Bible" written by Milind Watve which appeared in the "Classroom" section of *Resonance*, February 1996. As a teacher of chemistry, I read the author's observations on the textbook experiment to determine the percentage of oxygen in air, with great interest. I carried out this experiment carefully, as follows:

What immediately occurred to me was that drinking glasses usually have a tapered shape and therefore equal distances marked off on its wall may not represent equal volumes. Secondly, the candle inside the glass will take away some volume and therefore I assumed that introduction of a second candle, as reported by Watve, must have decreased the effective volume further and contributed to the increase in water level noted.

Luckily, I could get hold of a fancy, glass tumbler with vertical walls, which I used for my experiments. In order to eliminate the differences in volume due to the candlesticks, the following procedure was adopted. Three candle sticks with heights about half that of the tumbler were taken. These were placed inside the tumbler which was then filled with water. The candles were then taken out and the level of water inside the tumbler fell. The volume of water now represents the effective volume inside the tumbler when the three candles are covered. This height was marked off from the open end of the glass and divided into 10 equal parts to provide 10%, 20% . . . 100% readings by sticking a strip of paper along the wall with zero at the open end.

It appears that the decrease in the volume of air inside the glass depends on the number of candles lit (about 15% for each candle lit) and not on the oxygen content.

The three candles were stuck to the bottom of a trough and all were always present during the experiments so as to avoid any volume changes due to the number of candles present. One glass of water was then poured into the trough. One candle was lit and covered with the glass tumbler carefully. When the candle was extinguished, water rose in the tumbler and occupied about 15%



of the effective volume after a few minutes when the apparatus cooled down to almost room temperature. This was repeated several times, each time replacing the water at the bottom of the trough with a similar fresh quantity in order to avoid any effects of dissolved CO_2 etc., and lighting only one candle. Each time, the water level inside rose to occupy about 15 to 18% of the effective volume.

The experiments were then repeated, this time lighting two candles at a time. Water level in this case rose to occupy nearly 30% of the effective volume. The experiments were then repeated by lighting all the three candles. It was observed that the water level now reached about 45% of the effective volume. It thus appears that the decrease in the volume of air inside the glass depends on the number of candles lit (about 15% for each candle lit) and not on the oxygen content.

One possible explanation for the phenomenon may be as follows. One invariably takes a few seconds to lower the tumbler over the candle, during which time the air inside it expands and escapes at the bottom as indicated in *Figure 1*. When the mouth of the glass is closed by the water level and the candle stops burning, the air inside cools and contracts. Thus the rise in water level inside the glass represents the air that escaped due to expansion. When more candles are lit, the heat increases proportionately, driving away a proportionate amount of air from the tumbler. It so happens that the expansion loss per candle flame is about 15 to 18% and is close to the estimated oxygen content of air when only one candle is used. Water level should rise slowly during the experiment while the candle is still burning if it is due to the oxygen being used up. It was observed that there was little rise while the candle was burning, but the water level rose all of a sudden as soon as it was extinguished.

Further, when hydrocarbon in the candle burns, $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ (neglecting the volume of water produced as it is liquid) for every molecule of oxygen used, one molecule of CO_2 is produced and

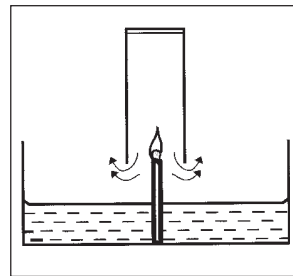


Figure 1 Air escapes at the bottom when a tumbler is lowered over a candle in a trough of water.

It so happens that the expansion loss per candle flame is about 15 to 18% and is close to the estimated oxygen content of air when only one candle is used.



When hydrocarbon in the candle burns, for every molecule of oxygen used up one molecule of CO_2 is produced and therefore there can be no change in volume.

there can be no change in volume. Indeed this has been observed to be the case when charcoal is burned inside a gas jar inverted over mercury. When water is used, it may absorb a portion of the CO_2 because of its greater solubility compared to air. It has also been documented that when a burning splinter is extinguished inside a closed gas jar, the remaining air contains only 2.5% CO_2 and 17.5% oxygen still remains!

Thus it appears that the experiment which has been taught to students over all these years does not represent the oxygen content of air at all!

Suggested Reading

**J R Partington. A Text-Book of Inorganic Chemistry. 6 ed. ELBS. 1963
Especially see pages 620 and 622.**

G S Ranganath, Raman
Research Institute, Bangalore

*Discussion of questions
raised in the Classroom
section of **Resonance**
Vol. 1, No.1.*

? In introducing the Bohr theory of the hydrogen atom, one makes a postulate that electrons in certain special orbits around the centre do not radiate. How does one reconcile this with what students have already learnt about radiation?

From Bohr's theory we can calculate $\nu = (E_n - E_{n-1}) / h$ the frequency of electromagnetic radiation emitted by the atom in a transition from n^{th} to $(n-1)^{\text{th}}$ state. For large values of n we find (verify) the radii and the energies of the n^{th} and $(n-1)^{\text{th}}$ states to be very nearly the same and ν becomes equal to the frequency of the orbital rotation of the electrons. This is the result to be expected from electrodynamics. Hence at large quantum numbers Bohr's theory agrees with classical mechanics. Incidentally, this is the central message of Bohr's Correspondence Principle.

Mohan Devadas, SBM Jain
College, Bangalore.

? As an example of special relativity in action, one quotes the case of the muon, with a half-life of less than ten nanoseconds (1 nanosecond = 10^{-9} sec). Travelling at almost the speed of light, it should only be able to cover a few metres in this time.



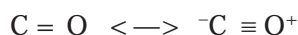
But cosmic ray physicists are able to detect muons which have travelled several kilometres, from the top of the atmosphere. Is this an example of length contraction or time dilation?

For an observer on earth it is an example for time dilation. However, for an observer on the muon it is an example for length contraction. Hence the answer is observer dependent.

? Carbon monoxide has a small dipole moment with the negative end at carbon. How can one explain this result?

In a heteronuclear diatomic molecule, A-B, the charge distribution would be unsymmetrical. The bond(s) would be polarised such that there is greater electron density near the atom with the higher electronegativity, say B. Atom B would therefore have an excess negative charge (δ^-) with a corresponding positive charge on A. The dipole moment of the molecule would then be $R\delta$, where R is the internuclear separation or bond length in A-B. The negative end of the dipole is obviously B.

Using the above arguments, the dipole moment of CO is expected to be fairly large with the negative end at oxygen. The experimental finding is different. One possible interpretation is that the canonical form (or resonance structure) with a negative charge on carbon makes a significant contribution to the electronic structure of CO.



The above explanation is only partly correct. There is a more important reason for the failure of the qualitative arguments. An assumption made in the preceding description of dipole moments is incorrect. The excess electron density was assumed to be a point charge at the nucleus. This is reasonable only if the charge distribution is symmetrical about the atoms. In reality, the electron density distribution is considerably uneven. This has to be taken into account in order to get the correct estimate of the dipole moment of a molecule.

J Chandrasekhar, Department of Organic Chemistry, Indian Institute of Science, Bangalore 560 012.

Discussion of questions raised in the Classroom section of Resonance Vol. 1, No.2.



The total dipole moment is the net sum resulting from positive nuclear charges, contribution from effective negative charges assuming the electron densities to be centred around the nuclei and a hybridisation correction.

The centroids of electron densities in 'pure' atomic orbitals such as s , p , d ... are at the corresponding nuclear centres. However, this is not the case in hybrid orbitals. One can readily see from the shapes of hybrid orbitals (e.g. sp orbital) with one lobe larger than the other that the centroids are shifted away from the nucleus. While computing the electronic contribution to the dipole moment, the magnitude of the charge as well as the average location have to be considered. The correction for the shift in the electronic centroid is sometimes called the hybridisation contribution to the dipole moment. The total dipole moment is the net sum resulting from positive nuclear charges, contribution from effective negative charges assuming the electron densities to be centred around the nuclei and a hybridisation correction. The individual terms cannot be experimentally measured. But they can be calculated using quantum chemical methods like molecular orbital theory. The computed data give us insights into the nature of bonding in molecules.

From such calculations, we get the following bonding description. The σ and the two π bonds of CO are polarised more towards oxygen, as expected. There are two other filled valence orbitals. For the sake of simplicity, they may be viewed as sp hybridised lone pair orbitals on oxygen and carbon. The centroids of these orbitals are located beyond the CO molecule, significantly away from the corresponding atoms. The centroid of the carbon lone pair is displaced to a greater degree. The resulting hybridisation correction is so large in this molecule that it reverses the trend from the effective charges on the atoms. The total value of the dipole moment is small and the carbon atom is at the negative end.

The consistency of the above description can be verified by considering the dipole moments of other molecules containing the C=O fragment. In molecules like formaldehyde or acetone, there is no lone pair on carbon. The total dipole moment is determined primarily by the effective charges on the atoms. The



oxygen atom is the negative end of the dipole in these type of molecules, as expected from electronegativity of the atoms involved.

? In a laser beam, many photons occur with the same direction, frequency and polarisation. Is this an example of Bose-Einstein condensation (BEC)?

Rajaram Nityananda, Raman Research Institute, Bangalore 560 080.

A laser beam indeed has many photons in the same quantum state, and these obey Bose statistics. However, Bose-Einstein condensation is an equilibrium phenomenon in which the particles are given enough time to exchange energy with each other or with some other system. The situation in a laser is quite different. The active medium is pumped, i.e. driven to excited energy state, by a source of optical, electrical, or even mechanical energy. It then produces the laser beam which escapes, surely a highly non-equilibrium situation.

However, if we allow photons to come to equilibrium with each other, the result is black body radiation. The distribution of particles as a function of energy is smooth, and does not have the spike at zero energy which is the signature of Bose-Einstein condensation. The reason is that as we cool the box the photons can disappear by absorption in the walls. The mean spacing between particles increases. This offsets the effect of the increase in the de Broglie wavelength on cooling. In the case of an ordinary gas the number of particles is fixed and hence also the mean spacing. (see the Research news item in the February 1996 issue). As we cool, we get condensation.

? A collection of non-interacting Bose particles exhibit BEC at low temperatures. How is this possible in the absence of interparticle forces? One usually assumes that an ideal gas does not condense.

Rajaram Nityananda, Raman Research Institute, Bangalore 560 080.

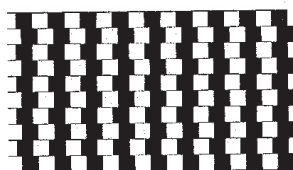
The question of how particles with no forces between them can



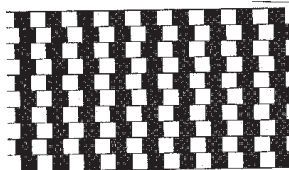
condense is indeed a deep one. The rules of quantum statistics tell us that the presence of one particle in a state can forbid (Fermi) or encourage (Bose) the presence of a second identical particle, which therefore "knows" about the existence of the first. While these rules of quantum theory have been known for a long time, there is no deeper model of this behaviour. The fact that a quantum system must be regarded as a whole, even when the parts are non-interacting, is called "non-locality" and it appears in other situations as well, eg. the famous EPR (Einstein, Poddsky, Rosen) paradox.



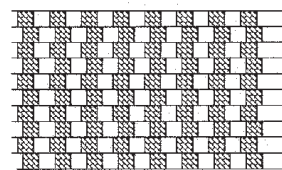
Optical illusions ...



(1)



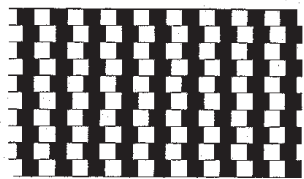
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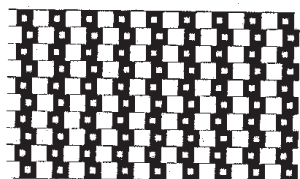
(3)

We see that the rows seem to alternatively converge to the right and left edges. This illusion is sensitive to the contrast and the pattern of the repeat unit. It is absent when there are grey squares as seen in No.3 above. When we compare Nos. 4, 5 and 6 the illusion appears to be greatly diminished in No.6 where the white dot is off centre. (T N Ruckmongathan, Raman Research Institute.)

(4)



(5)



(6)

