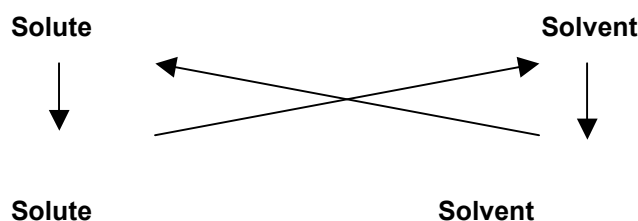


Teacher Notes

The gas we drink (Carbon dioxide in carbonated beverages)

About solubility and miscibility

The usual inter-particle forces are (i) electrostatic (Coulomb) forces (ii) Van der Waals forces in covalent compounds, and (iii) London dispersion forces. Solubility of a substance in a solvent depends on three interparticle forces as the following diagram shows:



These forces are: solute-solute, solvent-solvent, and solute-solvent. When these three types of forces are of comparable size, the substance is solvable in the solvent, otherwise it is not. As a result, substances with polar molecules are solvable in polar solvents, while substances whose molecules are non-polar dissolve in non-polar solvents. This is the general solubility principle: ***“similr dissolves similr”***.

Effect of temperature on the solubility of a gaseous substance in a liquid

The exothermicity or endothermicity of the dissolution process determines the effect of temperature on solubility. Most dissolutions of ionic (solid) substances in water are endothermic, and as a result increasing the temperature increases solubility. The dissolution of gaseous substances in a liquid solvent is an exothermic process; as a result increasing the temperature reduces solubility, so on heating gaseous bubbles form.

Developers: Georgios Tsapralis & Constantinos Kampourakis
Institution: Department of Chemistry, University of Ioannina
Country: Greece



University of
Ioannina

To this property of gases is due the phenomenon of **thermal pollution** of the environment. Hot aqueous wastes from factories that are disposed into rivers, lakes or the sea, reduce the solubility of dissolved in water oxygen causing a survival problem for living in the water organism.

Effect of pressure on solubility of gases in liquids

Increased pressure results in increased gas solubility in a liquid solvent. Carbonated beverages in closed bottles or cans are kept under high pressure. When we open them, the reduction of the pressure to the value of the atmospheric pressure has as result degassing of the beverage.

There is a corpuscular explanation of this effect by considering the dynamic equilibrium between the solute (the gaseous substance) and the solvent. At higher pressure, there is an increase in the frequency of gas particle collisions with the surface of the solution, and as result more solute particles enter the solution.

NOTE: Under usual pressure and temperature, and taking as measure the volume of carbon dioxide that can be dissolved in a fixed amount of water, the volume of oxygen (O_2) that can be dissolved is 30 times less, and that of nitrogen (N_2) is 60 times less.

In order to get carbon dioxide gas to dissolve in soft drinks, these beverages are bottled under significant pressure.

NOTE: The discussion of Henry's law and of the "other approaches" that follows is based on:

Hans de Grys, Determining the pressure inside an unopened carbonated beverage
Journal of Chemical Education, Vol. 84, No. 7, 1117-1119.

Henry's Law

With an advanced chemistry class, it is possible to resort to Henry's law to determine the pressure inside a closed can of a carbonated beverage. Unlike the other methodologies where only the gas in the headspace was at issue and the dissolved gas was not measured, in this case the opposite is true. The solubility term refers to only the gas that is actually dissolved in the sealed can. The challenge then is to completely degas a can of a beverage and measure the moles of carbon

Developers: Georgios Tsaparlis & Constantinos Kampourakis
Institution: Department of Chemistry, University of Ioannina
Country: Greece



University of
Ioannina

dioxide that were dissolved.

There are various means to this end, some of which provide more accurate measurements than others. Simple agitation is a favourite, although care must be taken not to spill any of the liquid contents. A high frequency shaker table can be used if one is available, with the mass of the can taken before and after shaking. Another approach is to heat the can gently with a hot plate and allow the gas to escape as the solubility of carbon dioxide falls with rising temperature. If the can is heated too much, a significant quantity of water vapor also escapes, foiling the attempt at measuring the mass of the CO₂ accurately.

Degassing by nucleation. Another method of degassing involves the introduction of nucleation sites into the beverage. Sprinkles of salt, sugar, or even whole candies have been shown to bring about rapid outgassing of carbon dioxide in a variety of sodas. The students must remember to measure the mass of these added substances and to add them slowly to prevent the dreaded bubble-over, they can be an effective tool.

Once the total number of moles of CO₂ have been found and the solubility calculated, it is a straightforward matter to use Henry's law to find the initial pressure that led to that level of carbonation:

$$C_{\text{gas}} = kP_{\text{gas}}$$

One needs only to find the solubility of carbon dioxide in the sealed can and the Henry's law constant (k , which is approximately 3.5×10^2 M atm for CO₂ at 25C), and one can solve for the pressure directly.

Other approaches

Aqueous carbon dioxide forms carbonic acid, so an acid–base approach may be used. First measure the pH of a newly opened beverage, then thoroughly degas it, and finally measure the pH again. Using the change in pH and the K_a for carbonic acid, one can calculate the concentration of carbonic acid present. From these data and literature equilibrium constant values, the molarity of the aqueous CO₂ dissolved in the beverage can be calculated.

Developers: Georgios Tsaparlis & Constantinos Kampourakis
Institution: Department of Chemistry, University of Ioannina
Country: Greece



University of
Ioannina

Taking into account the very weak nature of carbonic acid ($K_a = 4.3 \times 10^{-7}$ at 25°C) coupled with its very dilute concentration in the beverage (in the neighborhood of 1×10^{-4} M) could not possibly make any difference in the sea of stronger and more concentrated phosphoric acid already present in cola beverages. The result is that the phosphoric acid swamps any noticeable change in the $[\text{H}_3\text{O}^+]$ owing to the removal of the CO_2 .

Student Discovery of Gas Laws

M.R.P. Bopegedera

Journal of Chemical Education, 2007, Vol. 84, No. 3, 465-468.

The following article describes Boyle's original work:

Lewis, L. D. *J. Chem. Educ.* **1997**, *74*, 209–210.

A laboratory experiment book for high school and college general chemistry covers some of the gas laws

Randall, Jack. *Advanced Chemistry with Vernier: Experiments for AP, IB, and College General Chemistry*; Vernier Software and Technology: Beaverton, OR, 2004.

An article on the assessment of students' and teachers' understanding of gas laws is:

Lin, H.; Cheng, H.; Lawrenz, F. *J. Chem. Educ.* **2000**, *77*, 235–238.

For further bibliography on gas laws see the above paper by Bopegedera.

In this activity, the teacher lets students "discover" teaching gas laws in the laboratory using their own lab data. The subsequent lecture time is used for problem solving using gas laws. This pedagogy was effectively used with chemistry majors and nonmajors.

Developers: Georgios Tsapalis & Constantinos Kampourakis

Institution: Department of Chemistry, University of Ioannina

Country: Greece

The experiments are conducted with readily available, reasonably priced, Vernier software and laboratory equipment. Laboratory time is dedicated to collecting data, which is then exported to Microsoft Excel spreadsheets for graphing and analysis. (Logger Pro software provided by Vernier could be used also, if desired.)

Students analyzed their data individually, outside the lab period. They were directed to plot graphs and make inferences on the relationships between properties of gases based on these graphs, prior to attending a discussion session to go over their lab work. Each student submitted his or her lab report a few days after this discussion. Students conducted experiments and explored the relationships between the following properties of gases:

1. Pressure and volume (temperature and amount of gas held constant)
2. Pressure and temperature (volume and amount of gas held constant)
3. Volume and temperature (pressure and amount of gas held constant)
4. Pressure and the number of moles (volume and temperature held constant) to determine the universal gas constant.

Bibliography

- Atkins, W. P. (1989). *Physical Chemistry*. Third edition (Vol. I), pp. 13-17. Oxford University Press.
- Borgford, C. L., Summerlin, L. R. (1988). *Chemical Activities* – Teacher edition. American Chemical Society, Washington, D.C., pp. 5-7.
- Domin, D. S. (1999). A review of laboratory instruction. *Journal of Chemical Education*, 76 (4), 543-547.
- Graham, H. (1986). *Chemistry Counts*. Hodder and Stoughton, London Sydney, Auckland, Toronto, pp. 36-37.
- Johnstone, A. H., Al-Shuaili, A. (2001). Learning in the laboratory; some thoughts from the literature. *University Chemistry Education*, 5, 42-51.



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Kampourakis, C., Tsapalis, G. (2003). A study of the effect of a practical activity on problem solving in chemistry. *Chemistry Education Research and Practice* 4 (3), 319-333. ([http:// www.rsc.org/Education/CERP](http://www.rsc.org/Education/CERP))

Laugier, A., Dumon, A. (2003). Résolution de problème et pratique expérimentale: analyse du comportement des élèves en début seconde. *Chemistry Education Research and Practice* 4 (3), 335-352. ([http:// www.rsc.org/Education/CERP](http://www.rsc.org/Education/CERP))

Nussbaum, J. (1988). The particulate nature of matter in the gaseous phase. In Driver, R., Guesne, E. and Tiberghien, A. (eds), *Children's Ideas in Science*, pp. 124-144. Open University Press, Milton Keynes.

http://en.wikipedia.org/wiki/Carbonated_water

<http://en.wikipedia.org/wiki/Carbonation>

http://en.wikipedia.org/wiki/Soft_drink

Developers: Georgios Tsapalis & Constantinos Kampourakis
Institution: Department of Chemistry, University of Ioannina
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