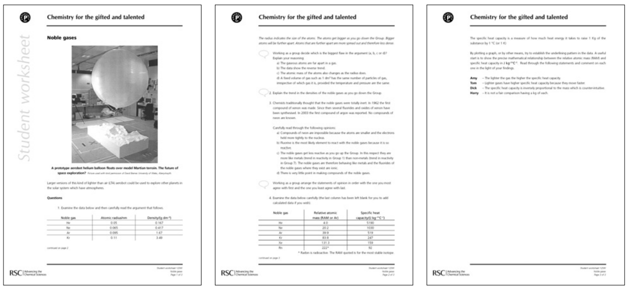
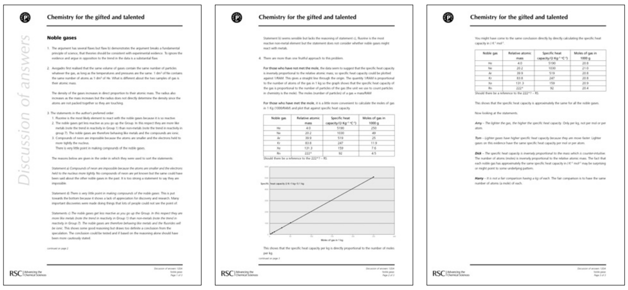
Noble gases



Student worksheet: CDROM index 12SW



Discussion of answers: CDROM index 12DA

Topics

Trends in the noble gases, spotting patterns in data and the reactivity of noble gases.

Level

Very able pre–16 students.

Prior knowledge

Simple kinetic theory, atomic structure, trends in reactivity in Groups 1 and 7.
The mole is useful for question 4 but very able students should be able to do without it.

Rationale

The activity sets some critical thinking and pattern spotting tasks in the context of the noble gases. The students are given data that can be manipulated to show a directly proportional relationship, they may well develop their skills at determining mathematical relationships between variables from graphs.

Use

This can be used as a differentiated activity for a group of very able students who already know or will readily acquire what the specification requires them to recall about the noble gases. It could be used as a whole group exercise with support for question 4, where the students could be prompted to plot specific heat capacity against 1/RAM. They could be asked to consider the statements as hints towards the answer.

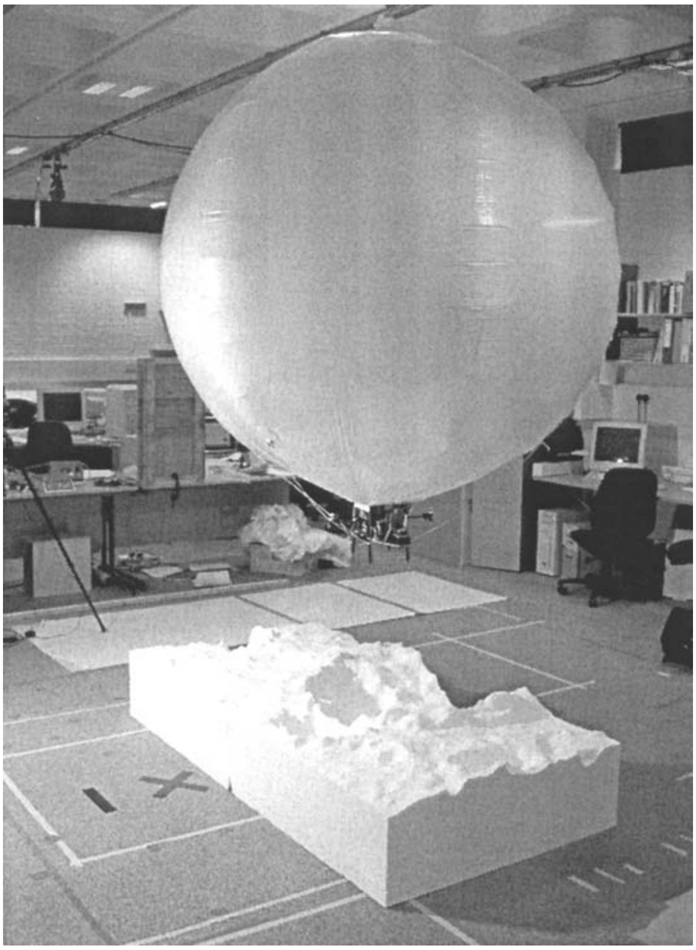
When the students have completed the worksheet they should be given the *Discussion of answers* sheet. They could check their own work or conduct a peer review of the work of another student or group.

Note

The specific heat capacity values quoted are measured at constant pressure. The average value for the noble gases is approximately 5/2 R J K^{-1} mol^{-1}. C_v values (specific heat capacity measured at constant volume) would be approx 3/2 R J K^{-1} mol^{-1} (for monoatomic gases) because no work is done against the external pressure as the temperature is raised because the gas is not allowed to expand.

Student worksheet

Noble gases



A prototype aerobot helium balloon floats over model Martian terrain. The future of space exploration? *Picture used with kind permission of David Barnes, University of Wales, Aberystwyth.*

Larger versions of this kind of 'lighter than air' (LTA) aerobot could be used to explore other planets in the solar system which have atmospheres.

Questions

1. Examine the data below and then carefully read the argument that follows.

Noble gas	Atomic radius/nm	Density/(g dm^{-3})
He	0.05	0.167
Ne	0.065	0.417
Ar	0.095	1.67
Kr	0.11	3.49

continued on page 2

The radius indicates the size of the atoms. The atoms get bigger as you go down the Group. Bigger atoms will be further apart. Atoms that are further apart are more spread out and therefore less dense.

1. Working as a group decide which is the biggest flaw in the argument (a, b, c or d)? Explain your reasoning.
   a) The gaseous atoms are far apart in a gas.
   b) The data show the reverse trend.
   c) The atomic mass of the atoms also changes as the radius does.
   d) A fixed volume of gas such as 1 dm^3 has the same number of particles of gas, irrespective of which gas it is, provided the temperature and pressure are the same.

2. Explain the trend in the densities of the noble gases as you go down the Group.

3. Chemists traditionally thought that the noble gases were totally inert. In 1962 the first compound of xenon was made. Since then several fluorides and oxides of xenon have been synthesised. In 2003 the first compound of argon was reported. No compounds of neon are known.

   Carefully read through the following opinions:
   a) Compounds of neon are impossible because the atoms are smaller and the electrons are held more tightly to the nucleus.
   b) Fluorine is the most likely element to react with the noble gases because it is so reactive.
   c) The noble gases get less reactive as you go up the Group. In this respect they are more like metals (note the trend in reactivity in Group 1) than non-metals (note the trend in reactivity in Group 7). The noble gases are therefore behaving like metals and the fluorides of the noble gases, where they exist, are ionic.
   d) There is very little point in making compounds of the noble gases.

   Working as a group arrange the statements of opinion in order with the one you most agree with first and the one you least agree with last.

4. Examine the data below carefully (the last column has been left blank for you to add calculated data if you wish).

Noble gas	Relative atomic mass (RAM or Ar)	Specific heat capacity/(J $kg^{-1}°C^{-1}$)	
He	4.0	5190	
Ne	20.2	1030	
Ar	39.9	519	
Kr	83.8	247	
Xe	131.3	159	
Rn	222*	92	

* Radon is radioactive. The Ar quoted is for the most stable isotope.

continued on page 3

The specific heat capacity is a measure of how much heat energy it takes to raise the temperature of 1 kg of the substance by 1 °C (or 1 K).

By plotting a graph, or by other means, try to establish the underlining pattern in the data. A useful start is to show the precise mathematical relationship between the relative atomic mass (Ar) and the specific heat capacity in **J kg^{-1}°C^{-1}**. Read through the following statements and comment on each one in light of your findings.

Amy – The lighter the gas, the higher the specific heat capacity.
Tom – Lighter gases have higher specific heat capacity because they move faster.
Dick – The specific heat capacity is inversely proportional to the mass, which is counter-intuitive.
Harry – It is not a fair comparison having a kg of each.

Noble gases

1. The argument has several flaws but flaw b) demonstrates the argument breaks a fundamental principle of science, that theories should be consistent with experimental evidence. To ignore the evidence and argue in opposition to the trend in the data is a substantial flaw.

2. Avogadro first realised that the same volume of gases contain the same number of particles whatever the gas, as long as the temperatures and pressures are the same. 1 dm^3 of Ne contains the same number of atoms as 1 dm^3 of He. What is different about the two samples of gas is their atomic mass.

   The density of the gases increases in direct proportion to their atomic mass. The radius also increases as the mass increases, but the radius does not directly determine the density since the atoms are not packed together so they are touching.

3. The statements in the author's preferred order:
   1. Fluorine is the most likely element to react with the noble gases because it is so reactive.
   2. The noble gases get less reactive as you go up the Group. In this respect they are more like metals (note the trend in reactivity in Group 1) than non-metals (note the trend in reactivity in Group 7). The noble gases are therefore behaving like metals and the compounds are ionic.
   3. Compounds of neon are impossible because the atoms are smaller and the electrons are held to more tightly the nucleus.
   4. There is very little point in making compounds of the noble gases.

   The reasons below are given in the order in which they were used to sort the statements:

   Statement a) *Compounds of neon are impossible because the atoms are smaller and the electrons held to the nucleus more tightly.* No compounds of neon are yet known but the same could have been said about the other noble gases in the past. It is too strong a statement to say they are impossible.

   Statement d) *There is very little point in making compounds of the noble gases*. This is put towards the bottom because it shows a lack of appreciation for discovery and research. Many important discoveries were made doing things that lots of people could not see the point of.

   Statements c) *The noble gases get less reactive as you go up the Group. In this respect they are more like metals (note the trend in reactivity in Group 1) than non-metals (note the trend in reactivity in Group 7). The noble gases are therefore behaving like metals and the fluorides will be ionic.* This shows some good reasoning but draws too definite a conclusion from the speculation. The conclusion could be tested and, if based on the reasoning alone, should have been more cautiously stated.

continued on page 2

Statement b) seems sensible but lacks the reasoning of statement c), fluorine is the most reactive non-metal element but the statement does not consider whether noble gases might react with metals.

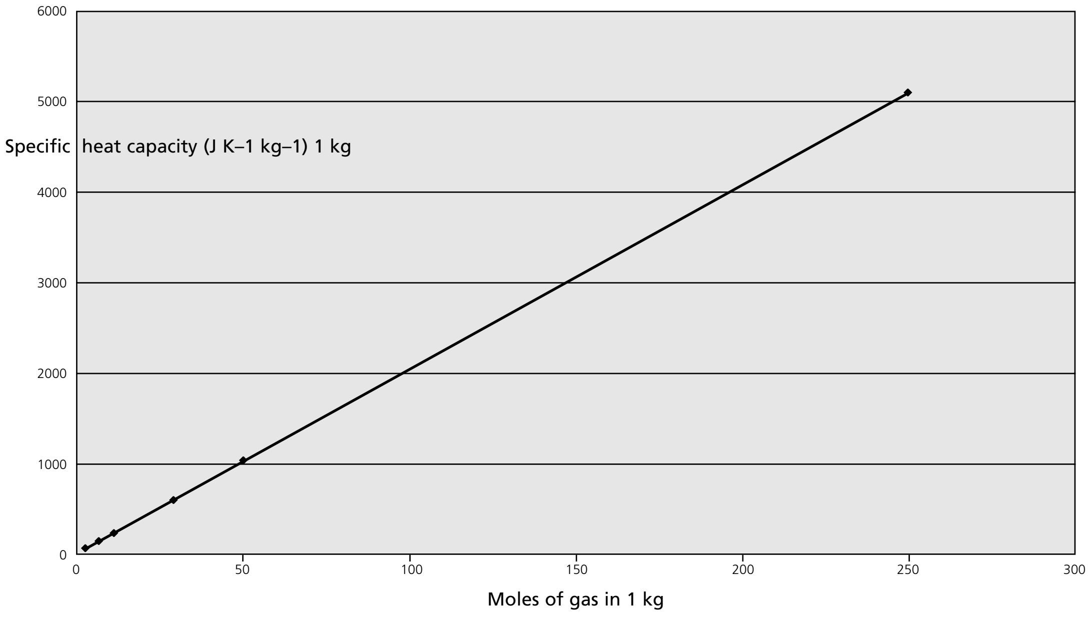
4. There are more than one fruitful approaches to this problem.

For those who have not met the mole: the data seem to suggest that the specific heat capacity is inversely proportional to the relative atomic mass; so specific heat capacity could be plotted against 1/Ar. This gives a straight line through the origin. The quantity 1/Ar is proportional to the number of atoms of the gas in 1 kg, so the graph shows that the specific heat capacity of the gas is proportional to the number of particles of the gas (the unit we use to count particles in chemistry is the mole). The moles (number of particles) of a gas = mass/Ar.

For those who have met the mole: it is a little more convenient to calculate the moles of gas in 1 kg (1000/Ar) and plot that against specific heat capacity.

Noble gas	Relative atomic mass (RAM or Ar)	Specific heat capacity/(J Kg^{-1} $^oC^{-1}$)	Moles of gas in 1000 g
He	4.0	5190	250
Ne	20.2	1030	49
Ar	39.9	519	25
Kr	83.8	247	11.9
Xe	131.3	159	7.6
Rn	222*	92	4.5

*Radon is radioactive. The Ar quoted is for the most stable isotope.



This shows that the specific heat capacity per kg is directly proportional to the number of moles per kg.

continued on page 3

You might have come to the same conclusion by directly calculating the specific heat capacity in J K^{-1} mol^{-1}.

Noble gas	Relative atomic mass	Specific heat capacity/(J Kg^{-1} $^{o}C^{-1}$)	Moles of gas in 1000 g
He	4.0	5190	20.8
Ne	20.2	1030	21.0
Ar	39.9	519	20.8
Kr	83.8	247	20.8
Xe	131.3	159	20.9
Rn	222*	92	20.4

*Radon is radioactive. The Ar quoted is for the most stable isotope.

This shows that the specific heat capacity is approximately the same for all the noble gases.

Now looking at the statements.

Amy – *The lighter the gas, the higher the specific heat capacity*. Only per kg, not per mole or per atom.

Tom – *Lighter gases have higher specific heat capacity because they move faster*. Lighter gases on this evidence have the same specific heat capacity per mole or per atom.

Dick – *The specific heat capacity is inversely proportional to the mass which is counter-intuitive.* The number of atoms (moles) is inversely proportional to the relative atomic mass. The fact that each noble gas has approximately the same specific heat capacity in J K^{-1} mol^{-1} may be surprising or might point to some underlying pattern.

Harry – *It is not a fair comparison having a kg of each.* The fair comparison is to have the same number of atoms (a mole) of each.