True / False statements and explanations:

1. The total number and type of atoms present are the same at the start and end of a reaction.

True. This is of course the basis of balanced equations. Matter cannot be created or destroyed and in chemical reactions atoms retain their identity (proton number) although they may change the number of electrons. It may be worth checking that learners understand the difference between chemical reactions and nuclear reactions, as they will no doubt have come across examples where the element identity does change.

2. The amount of substance, measured in moles, is the same at the start and end of a reaction.

False. Thermal decomposition reactions such as the breakdown of metal carbonates or catalytic cracking are good examples of why this is not the case:

$CaCO_3 \rightarrow CaO + CO_2$

$C_{10}H_{22} \rightarrow 2C_2H_4 + C_6H_{14}$

These are not the only examples, but if a substance breaks down into smaller substances then there will be more moles in the products than in the reactants. Conversely, addition reactions produce one product from two. An everyday analogy such as dismantling a bicycle helps to show why ‘amount’ is not conserved – from one bicycle you can obtain two wheels, one handlebar, one seat etc.

3. The total mass of reactants is equal to the total mass of products for any reaction.

True. This statement is inextricably linked with the first statement, since the atoms involved do not change their mass during a reaction. Learners may have become confused about mass loss due to reactions where gas is given off (this is a popular way of measuring reaction rate after all) so try getting them to imagine (or indeed demonstrate) what happens if a balloon is put over the end of the reaction vessel and the change in mass monitored.

4. The total volume of gas is the same at the start and the end of a reaction.

False. The two reactions used in statement 2 above also apply to this, since in both the decomposition of carbonates and cracking of liquid hydrocarbons there are no gases in the reactants. Similarly the reaction of acids with metals or metal carbonates provide simple examples.

5. The amount in moles is proportional to the number of particles for that substance.

True. This statement is likely to generate discussion over the meaning of the term 'particles'. When quantifying the amount of substance using the mole as a unit, it is important to be specific about whether you are referring to moles of atoms, moles of molecules, moles of ions or simply moles of a 'repeat unit' for giant structures. Either way this statement remains true due to the phrase 'proportional'. The number of carbon dioxide molecules in a mole is proportional to Avogadro's number; so is the number of oxygen atoms in a mole of carbon dioxide molecules.

6. One mole of methane molecules (CH_4) contains 1/5 mole of carbon atoms and 4/5 mole of hydrogen atoms.

False. The use of molecular modelling kits could be useful in explaining this to learners as it is a surprisingly common misconception. Demonstrate taking apart a model of methane so that learners can see how many atoms are produced; it is important that they are happy with the relationship between amount in moles and number of molecules so that they can see the two quantities follow the same rules. Everyday analogies may also be useful again – taking apart a bicycle does not produce 2/3 wheels and 1/3 frame!

7. One mole of methane molecules (CH_4) contains 1 mole of carbon atoms and 4 moles of hydrogen atoms.

True. Statement 6 and 7 are mutually exclusive and so the same explanation can be applied to both.

8. 100 cm^3 of methane gas contains the same number of molecules as 100 cm^3 hydrogen gas at room temperature and pressure.

True. It is surprising how often learners use the molar gas volume in equations without being fully aware of its implications in terms of the amount of substance. Diagrams which show the relative space between particles compared to the size of particles (the empty space in argon activity can be used for able learners) in a gas can help to explain this, along with the PhET simulation.

9. 100 cm^3 of methane gas at room temperature and pressure has the same mass as 100 cm^3 of hydrogen gas under the same conditions.

False. By calculating the relative formula masses of methane and hydrogen, it can be seen that statements 8 and 9 must be mutually exclusive. Molymods or differing size balls or marbles could be used to demonstrate two containers which contain the same number of particles in a given volume but which have a different total mass.

10. If 0.1 mol of magnesium atoms reacts with a solution containing 0.1 mol of hydrochloric acid, 0.1 mol of hydrogen molecules will be produced. (Hint – you may need to look up or work out the balanced equation for this reaction.)

False. This statement tests learner understanding of ‘excess’ which is often poorly understood despite being used fairly regularly as a technique for salt preparation or reaction rate measurement. The balanced equation for the reaction is as follows:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

It therefore follows that magnesium reacts with hydrochloric acid in a 2 : 1 ratio; HC*l* is a limiting reagent in this example as only 0.05 mol of magnesium will react with 0.1 mol of acid. Since the equation shows that one mole of magnesium reacts to produce one mole of hydrogen, the total amount of hydrogen produced in this case will be 0.05 mol. This can also be demonstrated using models to show the particles that are used up compared to the particles that are left behind, and again the bicycle analogy can be brought into play – having two frames and two wheels does not mean I can assemble two bicycles!

Supporting/further information

Creative Problem Solving – Argon (RSC)

http://www.rsc.org/learn-chemistry/resource/res00000654/argon?cmpid=CMP00000731

As mentioned above, this activity uses molar volume calculations to work out the percentage empty space in a sample of argon, highlighting the large volume of unoccupied space that leads to a constant molar volume regardless of the size of gas particle.

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Checkpoint Task

Bonding and structure

Answers

Unbreakable Rule Statements

A. The atoms of Group 2 elements have two electrons in their outer shell.

> This is not a guideline but relates to the position of elements in the periodic table. As learners are introduced to more complex ideas at A Level (such as s,p,d,f notation) they can grow doubtful of earlier, simpler ideas in case they turn out to now be ‘wrong’.

D. Oppositely charged ions attract.

> This is of course always true, but the statement is included for the same reasons as the one above.

E. Delocalised electrons are more stable than electrons in fixed atomic orbitals.

> Learners have probably only met delocalised electrons in metals and graphite at this stage, but this will become important in organic chemistry later in the course.

F. Energy is released when ionic bonds form.

> Always true: if separating ions means overcoming electrostatic attractions and an input of energy, the reverse must be true when ions come together to form a lattice.

G. In an ionic compound, ions are combined in proportions which balance out the electrical charges.

> Always true: ionic compounds cannot have a charge overall, but this tests learners’ understanding of the term ‘compound’ as they will have come across molecular ions.

H. Energy is needed to break covalent bonds.

> Always true, because an electrostatic attraction is being overcome.

I. Energy is required to form positive ions from atoms.

> Always true, for the same reasons as above.

L. Electrons shared between atoms (in molecular orbitals) are more stable than electrons in atomic orbitals.

> Always true but the wording may confuse students. This is linked to the idea in I – if energy is needed to pull apart the atoms in a covalent molecule, the electrons within the bonding orbital must be more energetically stable.

M. Electrons that are closer to the nucleus experience less shielding and are more strongly attracted than electrons further away.

> Always true; again because of the electrostatic attractions involved.

Rule of Thumb Statements

B. Noble gases do not form any types of bonds because they have full outer shells.

> Exception: Noble gases further down the group, such as xenon, do react with very reactive elements such as fluorine as they are able to accommodate more than eight electrons in their outer shell.

C. Ionic substances have higher melting points than covalent substances.

> Exception: This is usually true but not the case for giant covalent structures such as diamond, graphite and silicon dioxide.

J. Energy is released when negative ions are formed from atoms.

> Exception: Energy is usually released when anions with a single negative charge form. However, adding an electron to a negatively charged ion is always very endothermic and so formation of 2– or 3– ions is usually endothermic. In addition to this, the first electron affinity of some elements such as nitrogen, beryllium and noble gases are also endothermic.

K. Bonding within compounds is either ionic or covalent.

> Exception: Once again, the existence of molecular ions means this is only a rule of thumb – many common substances contain both covalent and ionic bonding. Additionally there are covalent molecules which readily dissociate in solution to form ions.

N. Exception: dative covalent bonds are formed when one atom donates a pair of electrons to an electron-deficient species.

> Exception: dative covalent bonds are formed when one atom donates a pair of electrons to an electron-deficient species.

O. Compounds are more stable than elements.

> Exception: The formation of some compounds requires the breaking of very strong covalent bonds – as a result, these compounds are generally less stable than the elements. Oxides of nitrogen are a good example of this; ethane and hydrogen iodide also have a positive enthalpy of formation.

P. Elements always react to form ions with noble gas electron configurations.

> Exception: Transition metals generally do not form ions with noble gas configurations as this would require the removal of a large number of electrons.

Q. Ionic compounds are formed when metals react with non-metals.

> Exception: Aluminium forms several covalent compounds. Ionic compounds can also be formed from the combination of ammonium ions with non-metal anions, and organic acids and amines can form ionic salts.

R. Covalent compounds are formed when non-metals react with other non-metals.

> Exception: Aluminium and beryllium form several covalent compounds. Ionic compounds can also be formed from the combination of ammonium ions with non-metal anions.

S. Hydrogen atoms form ions by losing one electron and becoming H^+.

> Exception: In metal hydrides, hydrogen atoms gain an electron to form H^- ions.

T. Within a covalent compound, all elements except hydrogen have eight electrons in their outer shells.

> Exception: Group 13 elements can only share three electrons and so have six electrons in their outer shells. Elements in Period 3 or below can have more than eight (PF_5, SF_6)

Supporting/further information

The Royal Society of Chemistry has produced some excellent classroom resources to help identify and address learner misconceptions about bonding and ion formation; the three resources most pertinent to the checkpoint task are given below.

Stability and reactivity:

http://www.rsc.org/learn-chemistry/resource/res00001103/stability-and-reactivity

This resource gets learners to think in further detail about the relative stability of atoms and ions as well as elements vs compounds.

Why do atoms form ions?:

http://www.rsc.org/learn-chemistry/resource/res00000111/afl-why-do-atoms-form-ions

This ties in very well with the resource above and can help learners think about ion formation and ionic bond formation in the context of energy changes and electrostatic attractions.

Ionisation energy:

http://www.rsc.org/learn-chemistry/resource/res00001101/ionisation-energy

This is a fairly challenging true/false exercise which learners can use to test their understanding of ion formation, again in terms of energy changes and electrostatic attractions rather than the octet rule.