

## Table 1: The expert observers' selection of key student alternative conceptions in chemistry.

These candidates for key (and “important”) student alternative conceptions were either chosen by researchers, or else I was able to unambiguously infer from what the researchers wrote that they so regarded them. (In some cases I have preserved their actual words.) Presumably they don't all hold the same criteria for their choices, and each had their own focus and their own framework of ideas, so these choices cannot strictly be compared. It is nevertheless interesting to see how they often made different but related choices, and how seldom two researchers picked the same one. The failure of any one researcher to select any particular alternative conception or to choose from any particular category of alternative conceptions should not be given any significance, as presumably few of them had a complete list of alternative conceptions in front of them to consider, and most were concerned with only a limited subset of chemistry.

For information about the entries in Table 1, see Appendix 2.

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- A.1.2 Matter can disappear. [Kind (04): Key]
- A.1.4.1 Matter is continuous, but contains particles; matter exists between atoms.  
[Kind (04): Key]
- A.1.4.1a The space between atoms and molecules is not empty. [Kind (04): Key]
- A.1.6 Particles may have macroscopic properties: they may burn, contract, expand or change shape. [Kind (04): Key]
- A.2.8 Gas behaviour is explained by attractive or repulsive forces between molecules.  
[Kind (04): Key]
- A.3.1.3 (Mass is confused with density.) [Kind (04): Key]
- A.3.2.1.2 The products of chemical reactions need not have the same mass as the reactants.  
[Schmidt (97): Key]
- A.5.1 Collisions between molecules cause heat. [Thomaz (95): Key]
- A.5.1.1 Heat has the properties of matter or substance. [Schmidt (97): Key]
- A.5.1.1.1 Heat can add weight to the object being heated. [Schmidt (97): Key]
- A.5.1.1.2 Heat is a substance residing in a body which can pass from one body to another, like a fluid. [Thomaz (95): Key]
- A.5.1.1.2.1 Heat is in the fuel being burned and is not formed during combustion.  
[Schmidt (97): Key]
- A.5.1.4 Heat is something that heats up other things; either the hot object or a substance given off by it. [Viennot (98), Important]
- A.5.1.6 Heat is a sensation. [Thomaz (95): Key]
- A.5.1.7a The state of hotness or coldness depends on the material from which a body is made. [Thomaz (95): Key]
- A.5.4.2.1 Heating a body always means raising its temperature. [Thomaz (93, 95): Key]
- A.6.1.1 Temperature is a measure of a body's heat. [Kesidou (93), Key]
- A.6.3 Like heat, temperature is a property of the material from which a body is made.  
[Thomaz (93): Key]
- A.6.3.1 Different materials (flour, nails, water) placed for a long time in a room which is

at a certain temperature remain at different temperatures.

[Thomaz (95): Key] [Viennot (98), Key]

- A.7.2.2 Collisions between particles cause heat.  
[Viennot (98): "Central misconception"]

*Table 1: Expert Observers' Selection, Cont.*

- A.8.2 Force is supplied to things, which contain it and use it up.  
[Hestenes (92): Key]
- A.8.3 Force causes motion. (Force is proportional to velocity.)  
[Hestenes (92): Key]
- A.8.4 Force is dominance; the bigger, faster, more powerful thing in an interaction exerts more force. [Hestenes (92): Key]
- A.9.1.1 Energy is the "life force". [Viennot (97): Key]
- A.9.3 Energy can disappear. [Kruger (90), Key]
- A.9.3.1 Energy is used up in processes. [Kind (04): Key]
- A.9.3.3 Energy is not lost but is exhausted in bringing about an effect.  
[Kesidou (93): Key]
- A.9.4.2 Energy is used to create chemical bonds. [Kind (04): Key]
- A.9.5.2 Chemical bonds stores energy. [Kind (04): Key]
- A.9.5.2.1 Energy is stored in "high energy" bonds such as ATP. [Kind (04) p.66: Key]
- A.9.5.2.2 Breaking chemical bonds releases energy. [Kind (04): Key]
- A.9.5.2.4 Fuel stores energy. [Kind (04) p.66: Key]
- A.9.7.1 Energy is "produced" [Kruger (90): Key]
- A.9.9.2 Energy and force are the same thing. [Kesidou (93): Key]
- A.10.1.1 There is only one kind of charge. [Arons (97): Important]
- A.10.1.1.1 Positive charge is actually a deficit of negative charge.  
[Arons (97): Important]
- A.10.1.3.1 Charge is used up in electric circuits. [Arons (97), Key]
- A.10.3.3 (Students fail to recognize that an ideal battery maintains a constant potential difference between its terminals.) [McDermott (92), Key]
- A.10.4.1 (Concept of a complete circuit not understood.) [McDermott (92): Key]
- A.10.4.2 ("Something" is not conserved in electrical circuits.) [Arons (97): Most Important]
- A.10.4.2.1 "Electricity" is used up in electric circuits. [Arons (97): C; Key]
- A.10.4.2.2.2 Current is used up in electric circuits. [McDermott (92): Key]
- A.10.4.2.3 Energy is used up in electric circuits. [Arons (97): Key]
- A.10.4.4 Direction of current and order of elements matters in simple circuits.  
[McDermott (92): Key]
- B.1.1.4 Atoms have electrons circling them like planets around a star. [Cros (86): Key]
- B.1.2 Atoms have the properties of bulk matter. [Kind (04): Key]
- B.1.3 Atoms are alive (because they move.) [Griffiths (89, 92): Key]
- B.1.3.1 Atoms are like cells with a membrane and nucleus. [Wheeler (78): Important]
- B.1.7.1 (Particles (atoms and molecules) may explode, burn, contract, expand and/or change shape.) [Kind (04): Key]
- B.2.1 Molecules are basic, simple, indivisible entities. [CH: Key]
- B.2.5 (Failure to distinguish Elements, Compounds and Mixtures in terms of atomic

- model.) [Kind (04): Crucial; “may largely determine which students can continue with chemistry after age 16.”]
- B.3.2 (Students confused – and experts divided - about whether to treat a mole as a number or a quantity of matter.) [Kind (04): Key]
- B.3.3 (Students unable to visualize, work with mole-size large numbers.) [Kind (04): Key]
- B.4.1 Solid, liquid and gas are three types of same substance. One disappears as the other appears. [Schmidt (97): Key]
- B.4.2 Solid, liquid and gas are different substances. One disappears as the other appears. [Kind: Key]

*Table 1: Expert Observers' Selection, Cont.*

- B.4.2.2.4 Bubbles from boiling water consist of oxygen and hydrogen gas. [CH: Key]
- B.4.3 Freezing and boiling are examples of chemical reactions; a phase change is a kind of chemical reaction. [Ahtee (98): Key]
- B.4.3.2 When reversibility of a chemical reaction is observed, it can be explained as phase changes which occur as the temperature fluctuates. [van Driel: Important]
- B.4.7.3 Freezing is like drying. [Schmidt (97): Key]
- B.5.1 Melting and dissolving are the same thing. [Lee (93): Key]
- B.6.1.2 Chemical reactions are reactions which produce irreversible change. [van Driel (98): Key]
- B.6.1.2.1 The original substance vanishes "completely and forever" in a chemical reaction. [van Driel (98): Key]
- B.6.1.2.2 Fuels are destroyed in burning or changed into something else. [Kind (04): Key]
- B.6.1.2.3 Physical changes are reversible while chemical changes are not. [van Driel (98): Key]
- B.6.1.4.3 Combustion is a change of state of matter – solid or liquid to gaseous. [Kind (04): Key]
- B.6.2.2 Chemical reactions are caused by active agents acting on passive agents. [CH: Key]
- B.6.2.2.1 Chemical reactions must be driven by external intervention, e.g. heat. [Cachapuz (87): Key]
- B.6.3.1a Mass is not conserved. The products of chemical reactions need not have the same mass as the reactants. [Schmidt (97): Key]
- B.6.3.8 (Role of oxygen in burning not recognized.) [Kind (04): Key]
- B.6.4.1.1 Energy is used up in chemical reactions. [CH: Key]
- B.6.7.1 Chemical equilibrium and a chemical steady state are static conditions. [Kind (04): Key]
- B.6.7.1.3 At equilibrium, most or all chemical reaction ceases. [CH: Key]
- B.6.7.2 (An equilibrium reaction is not seen as two separate reactions.) [Kind (04): Key]
- B.6.7.4.2 When the amount of a reactant is increased the rate of the forward reaction is increased but the amount of the reverse reaction is decreased.

- [Hackling (85): Key]
- B.6.7.4.6 When a system is at equilibrium and a change is made in conditions the rate of the favored reaction increases but the rate of the other reaction decreases.  
[Hackling(85): Key]
- B.6.7.6 (Le Chatelier's Principle held to always apply.) [Kind (04): Key]
- B.7.5 A candle burning is endothermic, since heat is needed to initiate the reaction.  
[deVos (86): Key]
- B.8.1 An acid is something which eats material away or which can burn you.  
[Hand (88): Key] [Kind (04): Key]
- B.8.1.1 Testing for acids can only be done by trying to eat something away.  
[Hand (88): Key]
- B.8.1.2 The difference between a strong acid and a weak acid is that strong acids eat material away faster than weak acids. [Hand (88): Key]
- B.8.2 Neutralization is the breakdown of an acid or something changing from an acid.  
[Hand (88): Key] [Kind (04): Key]
- B.8.3 A base is something which makes up an acid. [Hand (88): Key]

*Table 1: Expert Observers' Selection, Cont.*

- B.8.4 A base/alkali inhibits the burning properties of an acid. [Kind (04): Key]
- B.8.5 Hydrogen ions are present in acids, but acids remain molecular in solution. [Kind (04): Key]
- C.2.1.2.1 Electrons move through electrolytes by being attracted to positive ions in the solution. [Sanger (99): Important]
- D.5.4.2 The "driving force" in a chemical reaction refers to an external causative agent.  
[Cachapuz (87): Key]
- E.1.1.2 Atoms "own" their electrons. [Tabor (98a): Important]
- E.1.1.3 Atoms are like cells with a membrane and nucleus. [Wheeler(78)(?) Important]
- E.4.1. Atoms "want" or "need" to form bonds. [Kind (04): Key.]
- E.4.2.2 Atoms are held together because they share electrons, so sharing electrons is like a force. [CH: Key]
- E.4.5 Ionic pairs such as  $\text{Na}^+$  and  $\text{Cl}^-$  are molecules. [Kind (04): Key]
- E.4.3 There are only two types of bond: covalent and ionic. [Kind (04): Key]
- E.4.7 Covalent bonds are weaker than ionic bonds. [Kind (04): Key]
- E.4.5 Atoms are held together because they share electrons, so sharing electrons is like a force. [CH: Key]
- E.4.6 The central (first) element in a formula is more powerful, and is responsible for bond formation. [Kind (04): Key]
- E.5.2.1 The number of ionic bonds an ion can form is determined by the electronic configuration. [Taber (97): Key]
- E.5.2.2 Ionic bonds can only form between the electrons that have donated or contributed electrons. [Taber (97): Key]
- E.5.3.1 Ionic bonds can only form between one sodium ion and one chlorine atom, so ion interaction with other ions are "just forces", not bonds.  
[Taber (97): Key]
- E.5.6 Covalent bonds are weaker than ionic bonds, and break first on heating.  
[Kind (04): Key]