



# **We Lied to You**

**45 Lies Taught in VCE Chemistry • 2019 edition**

## About the author

James Kennedy is a British chemistry teacher and passionate chemistry spokesperson. He founded the chemistry outreach initiative Sincerely, Chemicals in 2017 and published *Fighting Chemophobia* in 2018. Since graduating from the University of Cambridge with a Master's degree in Natural Sciences in 2010, he has pursued a passion for science communication and science outreach by using festivals, lectures, seminars, conferences, posters and T-shirts to make chemistry more open and accessible for the public.

He is a vocal pro-chemistry advocate who writes articles online and speaks in radio and podcast interviews. James' first published book, *Fighting Chemophobia*, stemmed from a need for people to understand and cure chemophobia by seeing chemicals in a more rational light. He has been teaching for 8 years and researching chemophobia for 3 years. He lives with his wife and daughter in Melbourne, Australia.

# Foreword

This book is a collection of lies we taught to our Year 12 Chemistry students in their graduation year.

The lies include well-meaning simplifications of the truth, mistakes in the textbook, and, in a few extreme cases, blatant falsehoods.

This book isn't a criticism of the VCE Chemistry course at all. In fact, I wrote this book to demonstrate the overwhelming complexity of Chemistry and the consequential need to make appropriate omissions and generalisations during our teaching as we tailor our lessons to the appropriate year level of students. This is a legitimate practice called *constructivism* in pedagogical circles. (Look that up.)

Rules taught as true usually work 90% of the time in this subject. Chemistry has rules, exceptions, exceptions to exceptions and so on. You'll peel pack these layers of rules and exceptions like an onion until you reach the core, where you'll find physics and specialist maths.

Before you read this book, check out the University of Cambridge Chemistry Data Book here:

<http://www.cie.org.uk/images/164870-2016-specimen-data-booklet.pdf>

How many pages can you understand? I just want you to know where Chemistry's headed.

Chemistry is a set of *models* that explain the macro level sometimes at the expense of detail. The more you study Chemistry, the more precise these models become, and they'll gradually enlighten you with a profound clarity about the inner workings of our universe.

Enjoy this book. I hope it emboldens you to question everything you're told, and encourages you to read *beyond* the courses you're taught in school.

Let's go!

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# Part 1: Lies taught in year 12

## **LIE #1: IR Spectroscopy is qualitative**

Infra-red spectroscopy is taught as a “qualitative technique”. However, there's also a quantitative use for it: in breathalysers, a filter wheel selects an infra-red beam of light with a wavenumber  $3200\text{-}3550\text{ cm}^{-1}$  which corresponds with the region of the electromagnetic spectrum where O-H (alcohol) absorption takes place. Light passes through the sample and is detected at the photocell, which, with the help of a microprocessor, puts a blood alcohol concentration (BAC) value on the screen.

In this instance, where IR spectroscopy is used to find the amount of O-H (alcohol) absorption on a person's breath, it is a **quantitative** technique!



**LIE #2:       $PV=nRT$**

The Ideal gas equation relies on several assumptions we learned back in year 11:

- **Random motion of particles**  
*What about wind?*
- **Negligible volume of particles**  
*Particles definitely have non-zero volume!*
- **Exert no forces on each other**  
*But what about dispersion forces?*
- **Collide elastically with each other and the walls of the container**  
*Collisions are never 100% efficient. We know this because they generate heat, e.g. when inflating a bicycle tire.*
- **Kinetic energy of the particles is proportional to their temperature.**  
*This one is true!*

You can see that most of these assumptions are not true. The formula we'd need if we were to take all of these truths into account would be:

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

Calculating the values of a and b is tricky, too. Here are the formulae for those constants, a and b:

$$a = \frac{27}{64} \times \frac{R^2 T_c^2}{P_c}$$

$$b = \frac{RT_c}{8P_c}$$

We can combine these equations to obtain the real Ideal as equation:

$$\left(p + \frac{n^2 \frac{27}{64} \times \frac{R^2 T_c^2}{P_c}}{V^2}\right) \left(V - n \frac{RT_c}{8P_c}\right) = nRT$$

Because this equation is too complex to be of practical use for VCE chemistry students, we use the simplified version,  $PV=nRT$ , in VCE chemistry examinations.

**LIE #3: Insoluble substances don't dissolve in water**

Solubility is a continuum that's measured by a value called a solubility product, or  $K_{sp}$ .

Similar to equilibrium constants (or  $K$ ), the higher the  $K_{sp}$  value, the more soluble the substance is. No substance has ever been found with a  $K_{sp}$  value of zero. Even barium sulfate, which is considered to be very insoluble in water, has a  $K_{sp}$  of  $1.1 \times 10^{-10}$ .

We can use an ICE table to show exactly how much  $BaSO_4$  dissolves in water. One gram of  $BaSO_4$  in one litre of water would result in a concentration of  $0.00001054 \text{ M } BaSO_4 (aq)$  in the water.

This is small, but it's not zero.

“Insoluble” doesn't mean that zero solute dissolves.

#### **LIE #4: Indicators are a good idea**

Not really: pH meters give a much more accurate reading of pH than judging the colour of an indicator by eye. There are even automated titration machines for sale online that use pH meter instead of an indicator. Indicators have colour changes that are too broad or difficult to see, which causes errors when judging the end point.

#### **LIE #5: An acid is a proton donor**

Wrong again! An acid was only defined as a proton donor by Brønsted and Lowry in 1923. Many other definitions exist that are still in use.

Here are some alternative definitions of “acid”:

<b>Chemist</b>	<b>Year</b>	<b>Definition of “acid”</b>
Liebig	1838	hydrogen-containing substance
Arrhenius	1884	produce $\text{H}^+(\text{aq})$ in solution
Brønsted-Lowry	1923	donates $\text{H}^+(\text{aq})$ in solution
Lewis	1923	accepts a pair of electrons
Usanovich	1938	accepts negative species
Lux-Flood	1947	an $\text{O}_2$ acceptor

**LIE #6: That direct titration of Cloudy Ammonia® solution was a good idea**

Many schools do a titration of a cleaning product called Cloudy Ammonia to find the concentration of  $\text{NH}_3(\text{aq})$  in the product. This is bad practice because  $\text{NH}_3(\text{aq})$  is a weak base and should therefore be analysed using another technique called back-titration instead. Direct titration of a weak base doesn't give a clear end point.

**LIE #7: KOHES is the way to balance half equations**

KOHES only works for cells with acidic electrolytes. For cells with alkaline electrolytes, which sometimes appear in VCAA papers despite not being in the study design, you'll need to use KOHES(OH).

Here's KOHES(OH) explained:

1. Do KOHES as normal
2. Add the same number of  $\text{OH}^-(\text{aq})$  ions to each side of the half-equation to balance out the  $\text{H}^+(\text{aq})$
3. Remember  $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$  makes  $\text{H}_2\text{O}(\text{l})$ .

4. Cancel any  $\text{H}_2\text{O}(\text{l})$  that might be present on each side.

Although not explicitly taught in VCE chemistry textbooks, you'll occasionally be presented with alkaline cells where  $\text{KOH}(\text{s})$  is a necessary calculation step.

**LIE #8: Peak height on a chromatogram represents the concentration**

Wrong again. It's actually the area under each peak that represents the amount of component coming out of a chromatography column. VCAA just changed this to 'height' to make it easier to measure using a ruler in examinations.

The same goes for NMR spectra. You might have noticed that genuine low-resolution NMR spectra can have peaks due to 2 H that are taller than the peaks due to 3 H. Again, it's area under each peak that matters, not peak height.

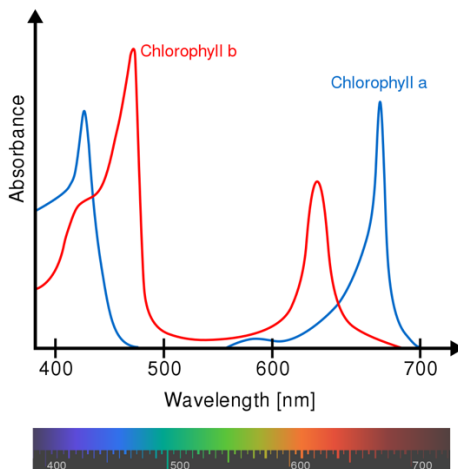
VCAA draws spectra by hand so this phenomenon never occurs in VCE questions!

## LIE #9: The colour wheel is a useful concept

I try to avoid mentioning the colour wheel when teaching spectroscopy even though it's mentioned in so many textbooks and worksheets.

The misconception here is that objects with a particular colour absorb the complementary colour on the other side of the colour wheel.

We just need to look at leaves to see this isn't true. Leaves are light green - and according to the colour wheel, they should be absorbing purple light. In reality, they absorb two colours: red and blue, but not purple. Here's the absorption profile for chlorophyll:



**LIE #10: We need to be able to interpret IR & NMR spectra accurately**

Unless you're going to become a specialist in spectroscopy, you're never going to need to understand spectroscopy in greater detail than is taught at VCE level. Most scientists just send their samples off to the experts for analysis. Even if you're using the machine yourself, modern spectrometers are linked to internet databases, and automatically interpret the spectra for you! They even tell you the name of the compound.

**LIE #11: All fragment ions in a mass spectrometer have a positive charge**

Usually, yes. However, sometimes, a fragment will become ionised with a 2+ charge as two electrons are knocked out of the molecule. This produces a set of superimposed 'shadow' peaks with half the  $m/z$  values of the originals. VCAA doesn't tell you this.

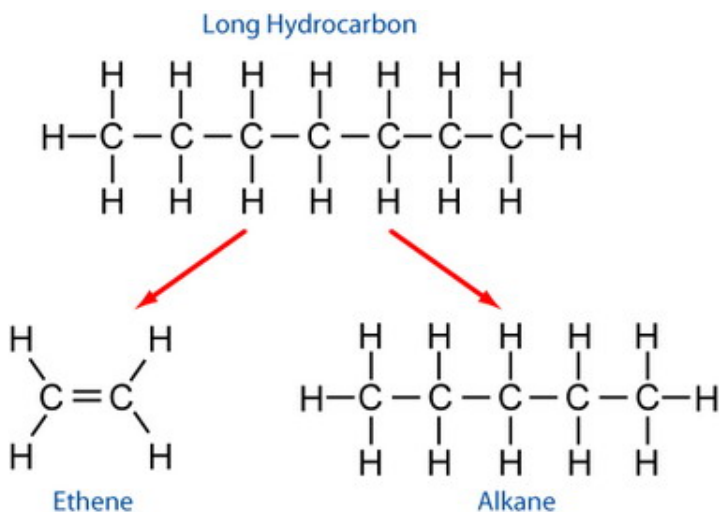


**LIE #12:** There are two reactions of alkanes:  
**combustion and substitution**

There's a third one: **cracking**.

Cracking is a reaction in which a long alkane is converted into one smaller alkane and one very small alkene, usually ethene.

Zeolite catalysts and a temperature of 500 °C are required.

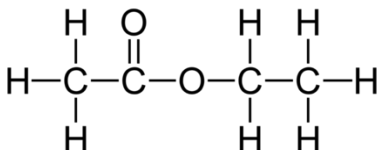


It's a very useful reaction in the petroleum industry and is taught in most curricula - but not in VCE.

**LIE #13: Ethyl ethanoate smells fruity**

Most esters smell fruity, but ethyl ethanoate is probably the least pleasant-smelling of all.

Organoleptic\* analyses report ethyl ethanoate as smelling like a "glue stick". Not fruity at all.



**LIE #14: E10 petrol contains 10% ethanol**

No. E10 petrol sold in Australia can contain *up to* 10% ethanol by volume. Producers whose fuel exceeds the 10% threshold face hefty fines.

**LIE #15: Bioethanol is carbon neutral**

No! If the processes of tilling, planting, growth, farming, fertilisation, irrigation, harvesting, transportation, fermentation and distribution were all 100% efficient, then bioethanol would be carbon neutral. But it's not. For a start, only around 10% of the carbon content in the plant actually gets converted into ethanol. The rest, which is mostly cellulose, hemicellulose and lignin, can't be digested by the enzymes used in the fermentation process and get wasted or burned off instead. Per life cycle, bioethanol emits almost as much CO<sub>2</sub> as fossil fuels.

**LIE #16: The semi-structural formula of oleic acid is  
CH<sub>3</sub>(CH<sub>2</sub>)<sub>7</sub>CH=CH(CH<sub>2</sub>)<sub>7</sub>COOH**

Unless it's an omega-3/6/9 fatty acid, it doesn't really matter where the carbon-carbon double bond is located. Structural isomers of oleic acid where the carbon-carbon double bond is located at a different carbon atom are still called "oleic acid".

**LIE #17:      Transesterification of triglycerides  
                 requires an OH<sup>-</sup>(aq) catalyst.**

Wrong. In fact, acid (H<sup>+</sup>) catalysts sometimes work better and it's a shame that VCAA doesn't agree.

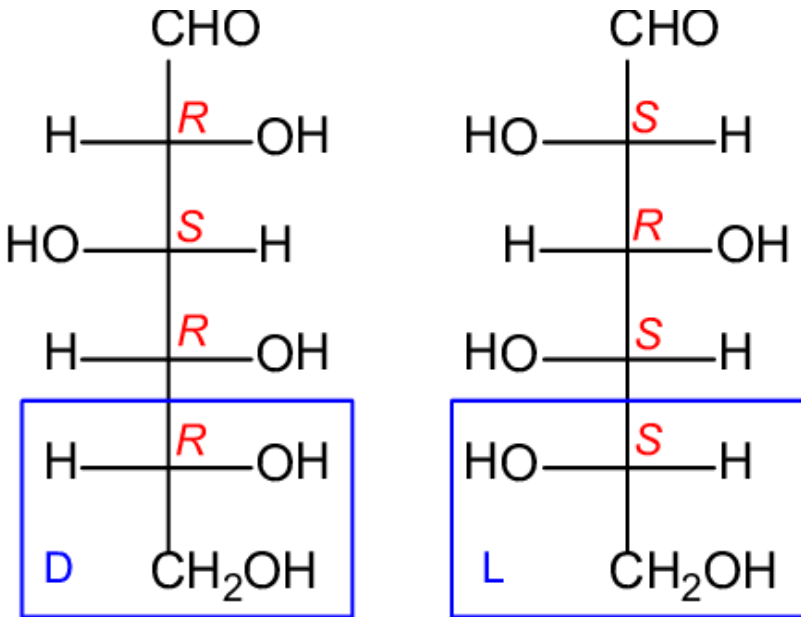
Reference: Nye, M. J. et al. "Conversion Of Used Frying Oil To Diesel Fuel By Transesterification: Preliminary Tests".  
Journal of the American Oil Chemists' Society 60.8 (1983):  
1598-1601. Web.

There exist enzymes that catalyse this reaction, but this method is not economically viable.

**LIE #18:      lucose exists in two forms: alpha - and  
                 beta-glucose**

lucose *mutarotates* between its many isomers.

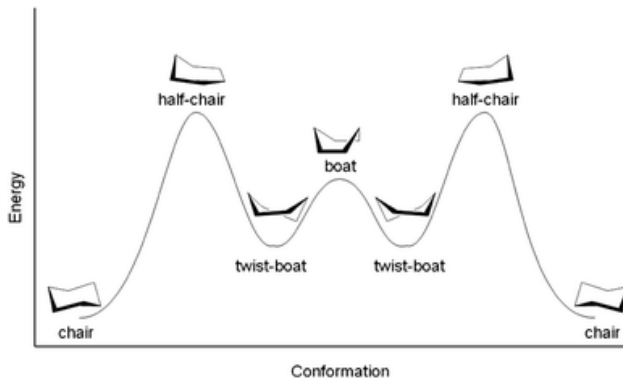
First, there are two **stereoisomers** called L- and D- glucose. D-glucose is found widely in living things while L-glucose is not.



L-glucose tastes exactly the same as D-glucose but cannot undergo glycolysis because the first enzyme (hexokinase) can't bind to it. The L-glucose stereoisomer is therefore a healthy, zero-calorie sweetener that tastes *exactly* like real sugar. It's also been shown to stimulate the release of insulin and has even been used as medication for diabetes mellitus. Second, you'll notice that both molecules were drawn *straight* above. Less than 1% of glucose exists as the straight ("open") isomer in aqueous solution. The straight glucose molecule reacts with itself to form several **cyclic isomers**, each of which is chiral:



into glucopyranose (cyclic glucose isomers) that themselves can adopt one of two stable **conformers** called “boat” and “chair”.



Finally, each isomer of glucose is subject to **rotational isomerism**. Rotation may occur around the O6-C6-C5-O5 torsion angle, termed the  $w$ -angle, to form three staggered rotamer conformations called *gauche-gauche* (gg), *gauche-trans* (gt) and *trans-gauche* (tg).

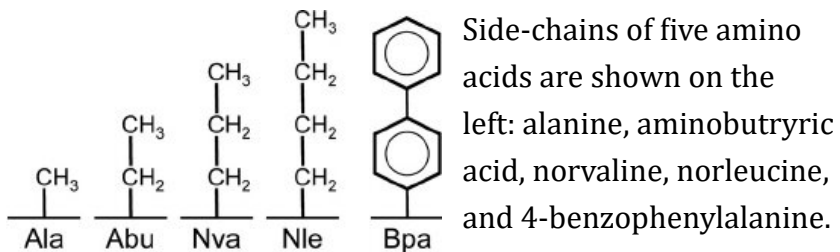
Overall, linear glucose can twist, turn and react with itself to form  $7 \times 2 \times 3 = 42$  different forms.

This figure of course excludes the many structural isomers of glucose that exist such as fructose. These, too, have more than one form in aqueous solution.

**LIE #19: There are 20 amino acids**

There are 20 amino acids that can be encoded by DNA codons. There are an additional 3 amino acids (formylmethionine, selenocysteine and pyrrolysine) that are formed **naturally** in our cells via post- translational modification.

In addition to these, there are about 900 naturally- occurring amino acids in various organisms, and another 120 artificial ones have been successfully incorporated into proteins.



There are also twin-amino acid stereocentres, and D- amino acids, which are stereoisomers of the “normal” L-amino acids. In total, there are well over 1000 amino acids.



**LIE #20: Denaturing enzymes alters their tertiary structure only**

Wrong. Both secondary and tertiary structure are disrupted. The textbook says that only tertiary structure is disrupted when enzymes are denatured.

**LIE #21: Hydroxyl groups are neutral**

Pure ethanol has a pH of 7.33. Hydroxyl groups are actually *very slightly* basic.

**LIE #22: Increasing reactant concentration always increases reaction rate**

Reaction rate is quite complex. Some reactions are what's known as *zero order*, which means that rate is independent of reactant concentration.

Enzyme-catalysed reactions tend to be zero order because the reaction rate is limited by the concentration of *enzyme*, not by the concentration of reactants. In such cases, increasing reactant concentration has no effect on reaction

rate!

**LIE #23: Atom economy is important**

Not really. By chasing atom economy, an industry might have less *mass* of waste, but the waste might be more harmful than from the conventional process.

For example, atom economy calculations persuade scientists to replace chlorine atoms with fluorine atoms just because they're lighter-even though they're much more dangerous for living things.

**LIE #24: You can change pressure while keeping temperature constant**

No. Think about a bicycle pump: when you inflate the tyre, pressure inside the pump and tyre is increased. This causes an increase in temperature.

When compressed gas such as  $\text{CO}_2(\text{g})$  in a fire extinguisher is decompressed, heat is absorbed and the temperature increases. Pressure is not completely independent of temperature.

**LIE #25: Alkenes are non-polar**

Many alkenes have a tiny net dipole that we ignore at VCE level. Propene has a net dipole of 0.366 D due to its asymmetrical shape, and *cis*-but-2-ene is more polar than *trans*-but-2-ene for the same reason.

**LIE #26: Weak acids don't fully ionise in solution.**

The percentage ionisation of a weak acid increases as you dilute the acid. For example, in a 0.0043 M solution of methanoic acid, 99% of the acid molecules have ionised.

**LIE #27: The electrochemical series is accurate**

It serves as a good approximation voltage between two half cells but has two major limitations that we don't talk about at VCE level.

First, it only works at standard conditions. To find  $E^0$  at non-standard conditions, we need to use the Nernst equation:

$$E = E^0 - \frac{RT}{nF} \times \ln \left( \frac{[\text{Red}]}{[\text{Ox}]} \right)$$

Second, there's overpotential, which is essentially the error between the value predicted by the Nernst equation and the value measured experimentally.

There are different types of overpotential: activation overpotential and concentration overpotential.

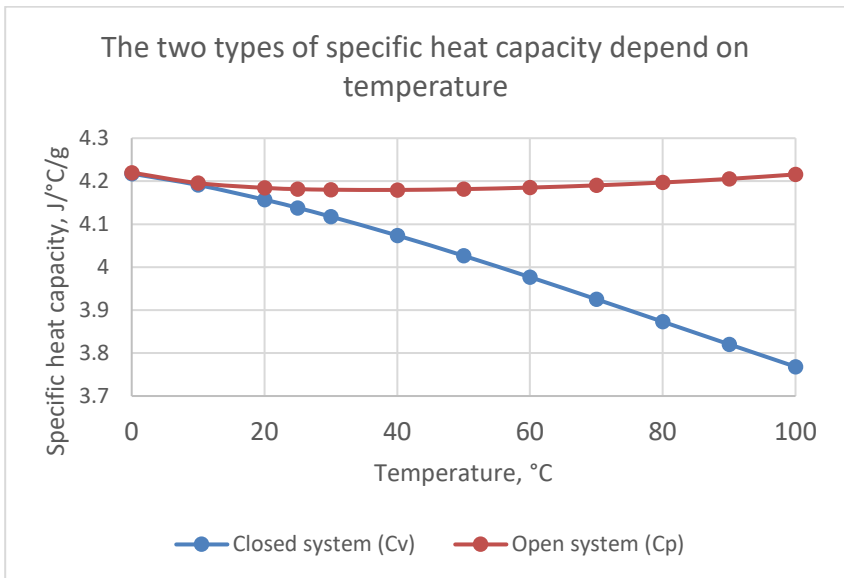
The discrepancy between the electrochemical series and the actual voltage obtained can be as large as one volt!

**LIE #28: Specific heat capacity of water =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$**

1

The specific heat capacity of liquid water varies with temperature. As water heats up above about  $50 \text{ }^\circ\text{C}$ , the hydrogen bonds become slightly more difficult to break. The specific heat capacity of water is not constant.

The graph below shows how specific heat capacity not only depends on temperature, but also on whether a system is open or closed.



## Part 2: Lies taught in year 11

### **LIE #29: Significant figures**

This is one of my favourites. Some students obsess over significant figures even though they're only worth one mark in the examination.

The rule taught at VCE level that “the answer is only accurate to the minimum number of significant figures used in the calculation” is only true for multiplication and division operations.

Different rules apply for addition/subtraction, multiplication/division, and log/antilog operations.

For example:

The pH of 1.23 M HCl(aq) is -0.090; and

The [H<sup>+</sup>] of pH 3.25 solution is  $5.6 \times 10^{-4}$  M

Learn more about the rules [here](#).

### **LIE #30: Aufbau principle works**

There are two exceptions to the Aufbau principle (copper and chromium) between hydrogen ( $Z=1$ ) and krypton ( $Z=36$ ). Exceptions to the rule become increasingly numerous after krypton.

About a quarter of the d-block and a quarter of the f-block don't follow the Aufbau rule. Examples include niobium, technetium, silver, gold and palladium. The reason for the deviation from the Aufbau rule is that the energy levels of subshells varies in complex ways as those subshells are progressively filled.

### **LIE #31: $3d^9$ is unstable**

Not always true. While  $3d^9$  is unstable in elemental copper, giving rise to its unusual electron configuration, it's important to know that there's an ***exception to the exception***: the copper(I) ion.

Electron configuration of  $Cu^+$  is  $[Ar] 3d^9 4s^1$ . In full, that's  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9 4s^1$ .

**LIE #32: Noble gases don't react**

Most noble gases form exotic compounds.

**Helium** forms  $\text{He}(\text{N}_2)_{11}$  “helium-nitrogen crystals” at extreme pressures above 100,000 atmospheres.

**Argon** forms  $\text{HArF}$  (argon fluorohydride) at very low temperatures (below 10 K).

**Xenon** forms  $\text{XeF}_4$  (xenon tetrafluoride) under extreme conditions to form a gas that's heavier than air and is safe to breathe. Steve Spangler used it on TV to make his voice deeper. Watch it on YouTube.

**LIE #33: Electrons have no mass**

VCE physics students know that electrons have small but significant mass of  $9.10938356 \times 10^{-27}$  kg.



**LIE #34: Protons and neutrons have equal mass**

Not exactly. Protons have mass  $1.6726219 \times 10^{-27}$  kg, and neutrons have mass  $1.674929 \times 10^{-27}$  kg. There's a difference of 0.138%, which we ignore at VCE level.

**LIE #35: There are three states of matter**

There are four fundamental states of matter: solid, liquid, gas and plasma. Plasma is formed when a gas is heated to a high enough temperature that the electrons become delocalised from the atoms they usually orbit. Examples include lightning, neon lights, electric sparks and plasma televisions.

There are at least **15 states of matter** including superfluids, Bose-Einstein condensates and glass. Learn more about these additional states of matter [here](#).

**LIE #36: Mercury, Hg, is the only liquid metal at room temperature**

Three metals are liquid at room' temperature.

**Mercury** is the most common liquid metal.

**NaK** is a little-known alloy of sodium and potassium. When these two metals are melted together, they cool to form an alloy that's liquid at room temperature. Its low melting point and high electrical conductivity makes it an excellent coolant in the latest fast neutron nuclear reactors.

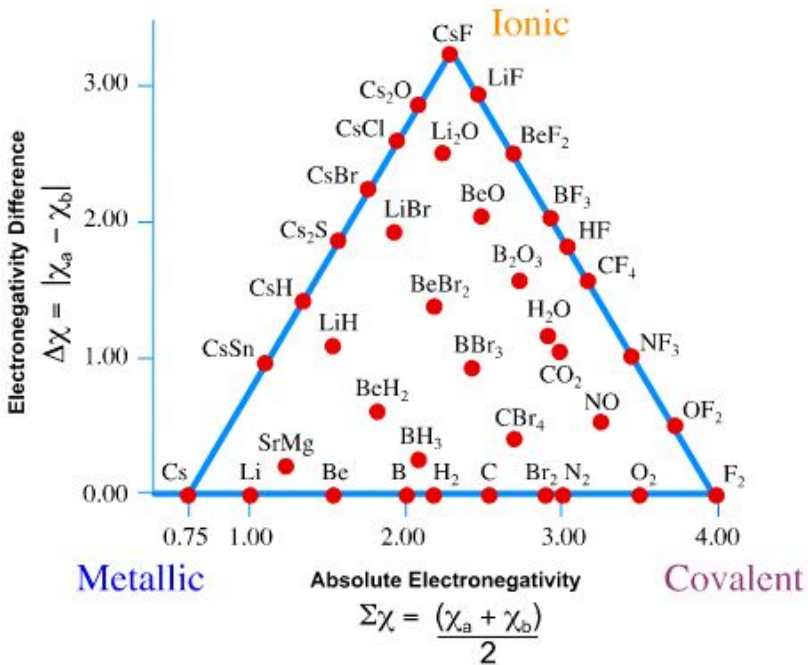
**allium** melts at 36 °C, which is about the same as chocolate. You can buy spoons made from gallium that look perfectly normal until you put them into lukewarm water. The spoon melts!



*A gallium teaspoon melting in lukewarm water*

**LIE #37: Ionic, covalent and metallic are three distinct types of bonding**

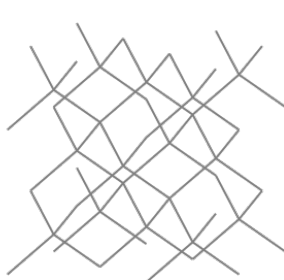
Bonding types actually on a spectrum called a **van Arkel triangle** shown below.



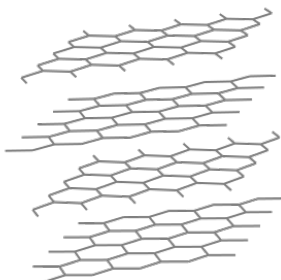
Carbon is an interesting example. Carbon is found in the middle of 'metallic' and 'covalent' on the bottom of the chart; and as such, has intermediate properties. Like a metallic substance, it has a high melting point and conducts electricity. Like a covalent substance, it's soft and dull.

**LIE #38: There are only three different forms  
(allotropes) of carbon**

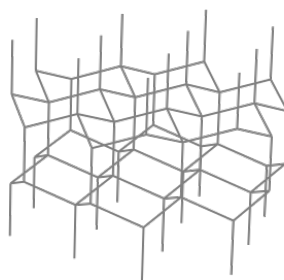
There are at least 10 allotropes of carbon. Eight are shown below.



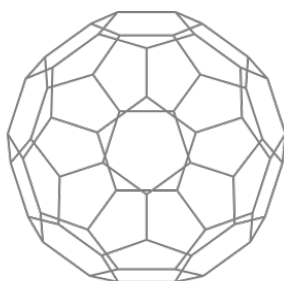
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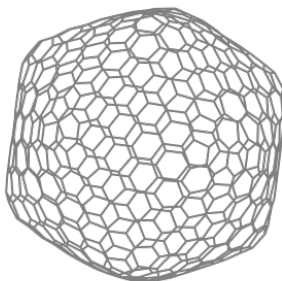
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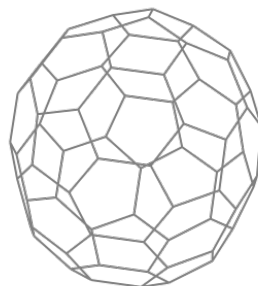
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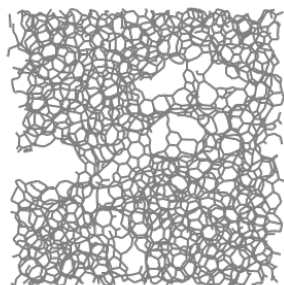
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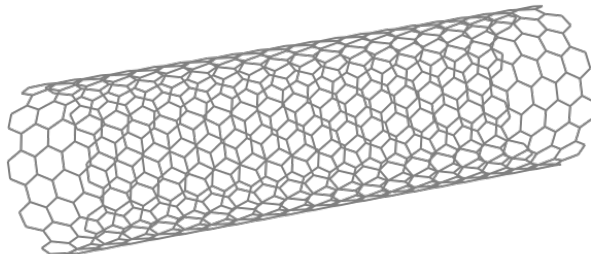
e



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g

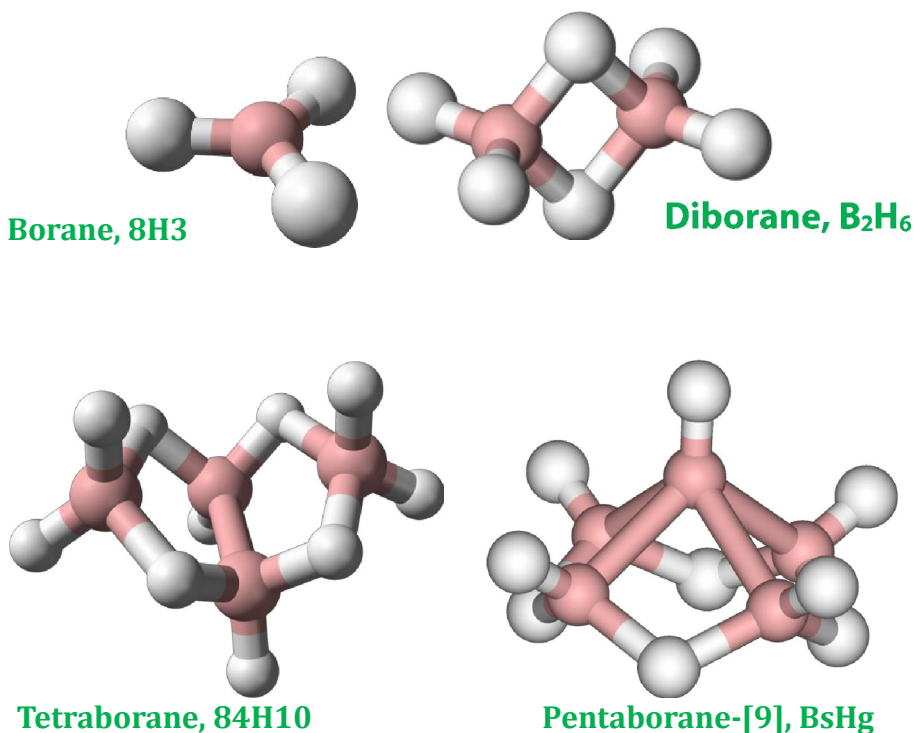


h

**LIE #39: BH<sub>3</sub> is stable**

The textbook implies that BH<sub>3</sub> is a stable compound even though it doesn't obey the octet rule. BH<sub>3</sub> is in fact very unstable and tends to dimerise and trimerise to become B<sub>2</sub>H<sub>6</sub> and B<sub>9</sub> and so on.

These compounds are called boranes, and they are neither stable nor normal.



**LIE #40: Organic molecules must be named with the lowest numbers**

Not true. There's a priority order that needs to be obeyed when naming organic molecules, and it isn't taught at VCE level. Benzene rings and carboxyl groups take priority, and side-chains (e.g. methyl groups) take the lowest priority.

Following the organic naming rules taught at VCE sometimes result in the wrong name being used.

For example:



**CORRECT NAME: 3-chloro-5-methylhexane**

**INCORRECT NAME: 4-chloro-2-methylhexane**

At VCE level, you learn that the second name is 'correct' even though this name unfortunately *doesn't* follow the IUPAC naming rules. VCAA has accepted both names in examinations.

**LIE #41: Ionic substances exist as giant lattices, not molecules.**

Wrong again. Potassium bromide, KBr, exists as discrete molecules in the gas phase despite being an ionic substance. Potassium bromide molecules are the most polar known molecules with a dipole moment of around 10.41 D.

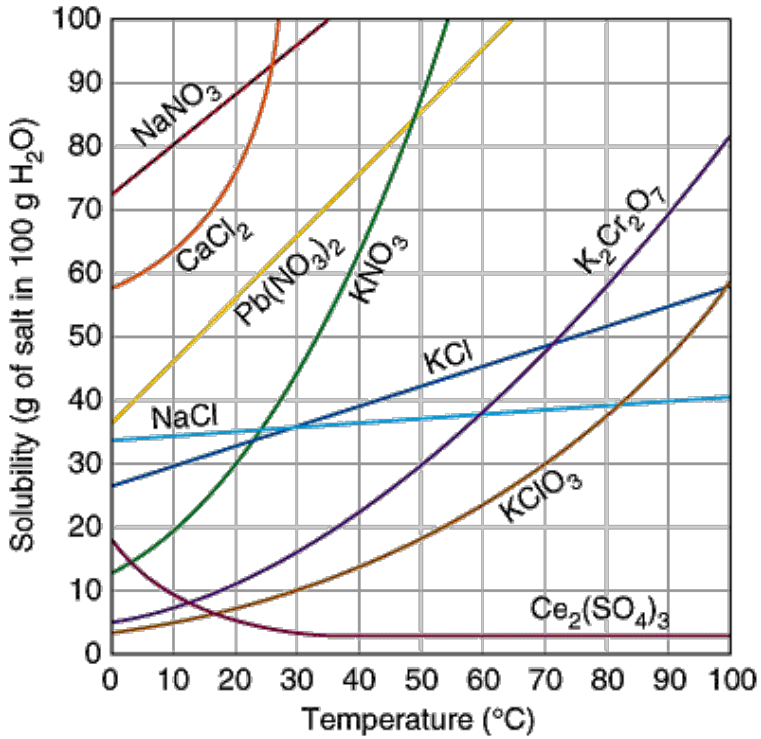
**LIE #42: Hydrogen bonding is strong**

Hydrogen bonding is about ten times weaker than most covalent bonds. We can prove this with a simple experiment: breaking the hydrogen bonds in water requires 100 °C temperature. Breaking the covalent bonds *within* the water molecules, however, requires about 1000 °C.

Hydrogen bonding isn't even the strongest type of *intermolecular* bonding. Ion-dipole bonds, which are formed when soluble salts dissolve in water, are stronger than hydrogen bonds.

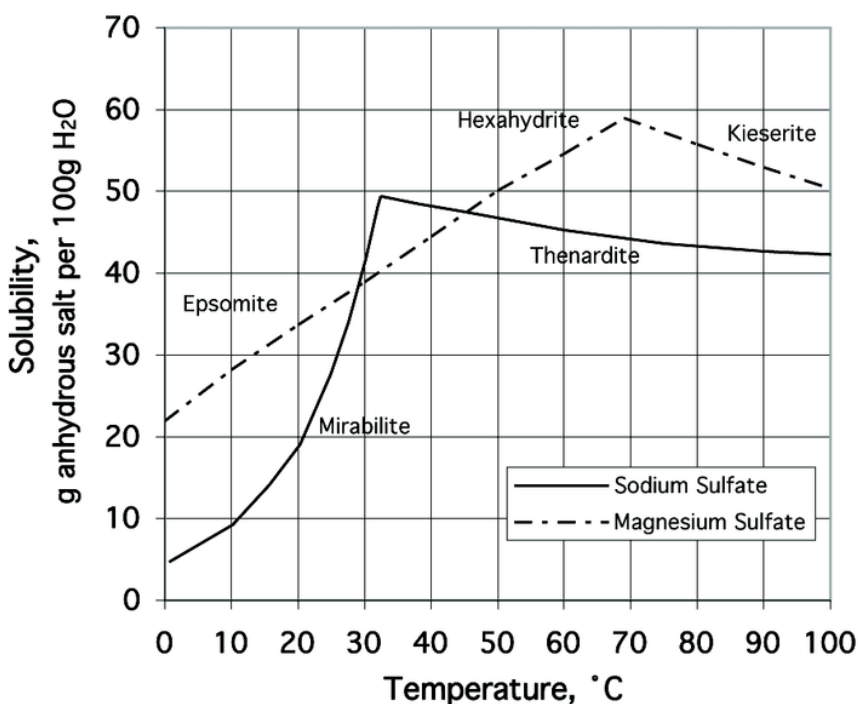
**LIE #43: Solubility of solids in liquids increases with increasing temperature**

While the solubility of most solids in liquid solvents such as water do increase steadily, cerium sulfate's solubility decreases with increasing temperature.





**Sodium sulfate's** solubility curve is even stranger. It reacts at temperatures of 32 °C or greater, favouring the anhydrous form over the decahydrate. Once the transition has been made, the gradient of the solubility curve changes dramatically, and drops off to an asymptote of around 45 g/100 mL.



Not all solids are more soluble in warm water than in cold water!

## **LIE #44: Water freezes at 0°C**

Pure water actually freezes at  $-1.3$  °C. This is very different from the 0 °C value given in our textbooks and encyclopaedias because the freezing temperature of water can be increased by the presence of impurities and rough solid surfaces that act as ice nuclei. These ice nuclei are so ubiquitous in our environment (e.g. particulate pollution or sufficiently rough surfaces of water containers) that water freezes at its highest possible temperature, 0 °C, most of the time.

You can do this experiment at home with supercooled water. Take a bottle of pure water (the cheapest mineral water will do because this tends to be relatively pure reverse osmosis water) and put it in the freezer. After several hours, gently remove the bottle from the freezer and hit it hard on the table. The agitation will trigger a sudden nucleation of ice crystals inside the bottle. Ice will appear to 'grow' inside upon impact.



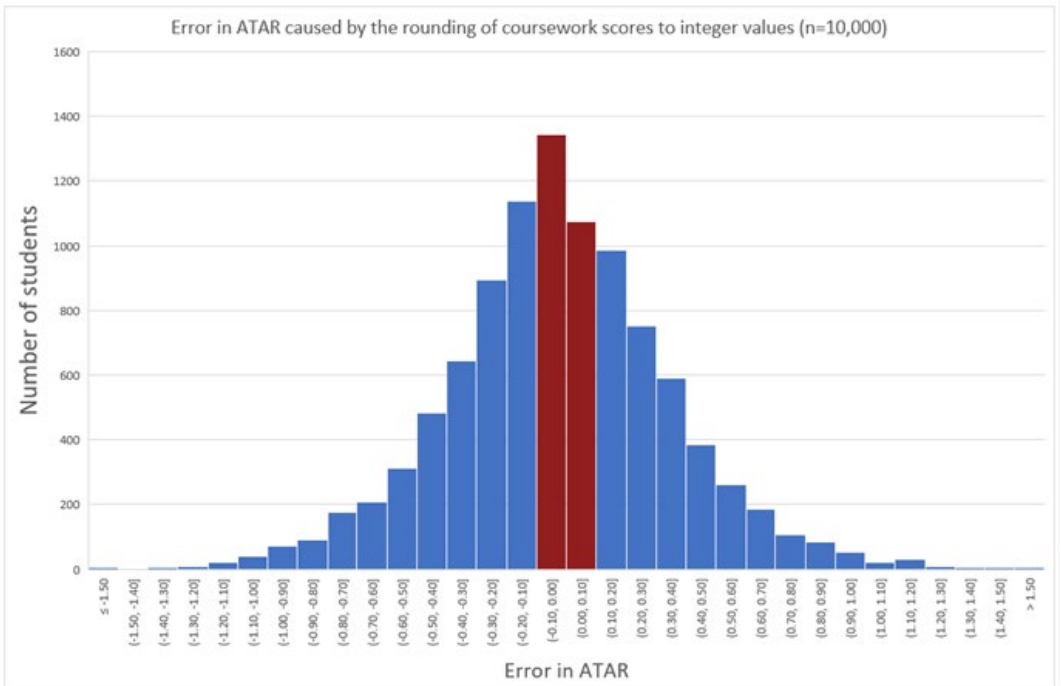
*Supercooled water freezes upon contact with solid ice*

**Reference:** [Moore, Emily and Valeria Molinero. "Structural Transformation In Supercooled Watercontrols The Crvstallization Rate Of Ice". \*Nature\* 479 \(2011\): 506. Web. 4 Nov. 2016.](#)

## LIE #45: Your ATAR is statistically significant to two decimal places

Teachers are required to re-scale your raw SAC marks to new maximum integer values for reporting to the VCAA via VASS. Decimal places emerge in the process, which are then rounded to integers (as required by the VCAA).

Each outcome score therefore has the potential to be increased or decreased by 0.5 marks with uniform distribution  $X \sim U(-0.5, 0.5)$ . These rounding errors compound to have an interesting effect on students' ATARs.



The compound effect of the rounding of each of your outcome (SAC) scores to integers out of 30 (or 50) results in statistically significant error to students' ATARs. An analysis I performed in October 2019 showed that:

- The decimal places on an ATAR are random;
- Only 71% of students' ATARs were correct to two significant figures; and
- The only way to guarantee that 100% of students' ATARs are reported accurately is by reporting them to the nearest even integer, i.e. to multiples of 2.

~THE END~

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