

## Designing Core Concepts for a Tertiary Basic Chemistry Course

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Abstract: A curriculum framework is proposed for the tertiary 'chemistry fundamentals' course based on Atkins' interrelated core chemical concepts. It is suggested that this course should not only provide a learning platform for 'basic chemistry', but should also show how chemistry exercises a crucial role in sustainable natural resource management and therefore, in sustaining the environment and addressing climate change. Further, it should encompass the principles of 'sustainable chemistry' and how these lead to a sustainable chemical industry and the wider chemical enterprise. The proposed course lends itself to a variety of learning methodologies and assessment procedures in harmony with contemporary pedagogy of 'effective teaching for constructive learning'. It can also easily be constructed into modules and delivered and assessed online. Based on our experience, we believe that the major advantage of this course, compared with most 'basic chemistry' courses previously and currently delivered, is that by acquiring knowledge of a relatively few 'core chemistry concepts', students are able to at least have a superficial understanding of contemporary major advances in chemistry and its associated technological developments and thus, it activates their interest in pursuing 'chemistry' as the main component of a rewarding career.

Key Words: Chemistry, Tertiary Course, Core, Basic, Concept, Design.

## INTRODUCTION

The 'core concepts', now called 'cornerstone concepts', of the tertiary 'chemistry fundamentals' course continue to be debated as the diversity of student cohorts taking this course continues to widen both in numbers, educational background and quality. The one semester course is intended for students enrolled in sciences other than chemistry and has to provide knowledge of sufficient basic chemistry to support the needs of many other sciences, most notably, the biological (life) sciences. Also, there has been protracted discussion on the curriculum of the traditional (2 semester) Chemistry 1 course, intended for chemistry majors, with concerns that since this course has not been reviewed in depth in India for at least 15 years (The University Grants Commission did it at national level in 1990's) and in Australia for at least 3 decades, it may no longer be revealing the 'richness' and 'relevance' of chemistry to contemporary



Figure 1. Atkins' core chemical concepts

students. This is evidenced by the unilateral decrease in the number of science students opting to undertake chemistry as a major over the last decade. These concerns initiated the design of an alternative curriculum framework for the tertiary Chemistry 1 course [1], based on three contemporary educational theories – those of Atkins, Lawton and Fensham. The proposed curriculum framework indicated that in addition to delineating the principal concepts of chemistry, it is also important to emphasise that chemistry has social, economic, ethical and environmental responsibilities and accountabilities which, when highlighted, counteract the negative image that chemistry has in the general community and thereby enhance its benefits to society.

Atkins [2] has suggested that nine core concepts form the basis of chemical knowledge (Fig.1).

These are essentially the cornerstone concepts of both the (Australian) one semester 'Chemistry Fundamentals' course and the two semester 'Chemistry Foundation' course for chemistry majors and form the main framework of these curricula [3]. Atkins' core chemical concepts are intended not only to simplify understanding of chemical principles, but also to engage the interest and curiosity of students and people generally in chemistry and to promote understanding and appreciation of the many benefits which it offers to the global society. Also, a wider understanding of these concepts endorses chemistry as the 'central empowering science' and as 'quantifying biology' and forms the basis of understanding 'sustainability science'.

This paper discusses a curriculum framework for the tertiary one semester 'Chemistry Fundamentals' course based entirely on Atkins' core chemical concepts. It is shown that judicious use of examples of each of these nine concepts allows the major areas of chemistry to be discussed at an elementary level. Also, frontier concepts can be introduced as emerging from these basic concepts, so as to project the fascination of chemistry and promote student engagement and interaction. Particular emphasis should be given to those basic concepts which impact directly on the operations of the global chemical industry and empower environmental sustainability.

## SCOPE OF CHEMISTRY – THE CENTRAL ENABLING SCIENCE

The introduction to the tertiary 'Chemistry Fundamentals' course should emphasise that chemistry is the central enabling science since it strongly impacts upon many other sciences, most notably biology, biotechnology, and pharmaceutical and materials science. These interactions are shown in Fig. 2.



Figure 2. The scope of Chemistry

Since chemistry is recognised as the foundation molecular science, it impacts on environmental and sustainability science and adds scientific credibility to the present climate change and environmental sustainability debates [4]. Chemistry is the essential precursor of chemical engineering and the reference base of materials science. Chemistry has long had a controversial role in food science, particularly with respect to artificial food additives and, more recently, in conjunction with the genetically modified foodstuffs debate. Chemistry is largely responsible for revolutionising forensic science following the acknowledged success of DNA fingerprinting. Chemistry impacts directly on the health sciences, not only with respect to the perennial quest for cheaper, more effective pharmaceuticals, but also in providing basic chemistry training for health professionals, particularly those involved in MRI scanning diagnosis. Overall, the course introduction should emphasise that studying chemistry and appreciating its richness and rigour can lead to a variety of rewarding careers, both research orientated, chemical industry orientated and teaching orientated. Further, the growing concern for global environmental sustainability [5] and the ever-increasing significance of materials science in the development of cutting edge technologies [6] underline the importance of designing improved foundation studies in chemistry to support student understanding of these developments.

## CHEMISTRY: THE PROPERTIES & STRUCTURE OF MATTER

An equally important aspect of the introduction to a 'Chemistry Fundamentals' course is to give a short but concise definition of chemistry as the 'properties and structure of matter', which immediately emphasises that the properties of matter are aligned with its molecular structure and with the extent of intermolecular interactions. Also, chemistry is a quantitative science and is governed by measurements which only have meaning when accompanied by units. This leads to a discussion of the SI unit system, the base SI units and the associated derived units. Special significance must be accorded to the 'mole' as the fundamental unit of chemistry. A brief discussion of 'precision' and 'accuracy' of measurements is also appropriate. Further, it must be emphasised that understanding chemistry requires some knowledge of basic mathematics, particularly 'scientific notation', algebra, rearranging and solving equations and basic calculus.

Like all sciences, chemistry has its own language and a unique nomenclature system, which is used throughout the course and with which students must become familiar and use. Some common words such as 'preparation' have a different meaning in chemistry to that in everyday usage.

Also, it should be emphasised that chemistry is a vast subject which has traditionally been divided into branches: 'inorganic', 'physical', 'organic' and 'analytical'. It is now recognised and accepted that the boundaries between these branches are becoming increasingly blurred and new branches such as 'green chemistry' and 'chemical education' have prominence. Indeed, it can be argued that 'biochemistry' is a branch of chemistry, but because of its prominence in the life sciences, it is generally considered an independent science.

Overall, the introduction to a tertiary 'Chemistry Fundamentals' course must convey to the students not only the richness and rigour of chemistry, but also that chemistry is at the forefront of scientific knowledge and is the enabling force driving technological development of a sustainable future for the environment and for humanity.

The proposed curriculum framework embraces the nine core concepts of chemistry so eloquently, as described by Atkins, and emphasises the connectivity of these concepts so as to provide more than a superficial understanding of chemistry.

## ATOMS

Atkins has described 'atoms' as the currency of discourse in chemistry. This is an apt description since the economics of the chemical industry and, more recently, the effectiveness of 'green chemistry' are based on 'atom economy' principles. Atkins points out that 'atoms are chemical accounting devices since is based on their existence stoichiometry and immutability in chemical reactions'. Hence, the 'Chemistry Fundamentals' course must not only highlight the fundamental concept that 'matter is composed of atoms', but also must emphasise the paradox that matter has 'bulk' despite being almost empty space.

An atom is simply described as comprised of a small, dense nucleus made up of positively charged protons and electrically neutral neutrons. Most of the mass of an atom is contained in the nucleus, which is surrounded by much larger extra-nuclear space that contains negatively charged electrons, the number of which is equal to the number of protons in the nucleus. It must be emphasised that it is the number of valence electrons in the outermost shells of atoms that define chemical properties. It is the valence electrons that are involved in chemical bond formation and electron transfer is critical to an explanation of chemical reactions. Thus, the electronic configuration of atoms, particularly with respect to identification of 'core' and 'valence' electrons, is a critical and defining property of atoms and their chemical behaviour.

Some 'frontier science' examples should be discussed based on knowledge of the structure of atoms, such as 'atom splitting' – leading to nuclear energy production, radio-isotope production, radio-carbon dating and nuclear waste production and nano-technology [7, 8] – leading to the production of 'smart materials', semi/super conductors and conducting synthetic polymers (Fig. 3). Also, atomic level manipulation of biological systems is now possible, leading the way to synthetic biology under "controlled conditions" and biodegradable engineered materials that are lighter, stronger and more resilient [9].

## NANOTECHNOLOGY – Control of Structure/Specific Properties



## Figure 3. Nanotechnology – Control of atomic structure

## **ELEMENTS**

Elements are composed of atoms of the same type and since there are more than 100 types of atoms, there are more than 100 known elements. Atkins has labelled the periodic table as 'the most striking icon of chemistry', since it shows that the elements group into families based on common electronic structures and that trends in physical and chemical properties of the elements and their compounds exist both across periods and down groups. Atkins has quite simply explained the uniqueness of the periodic table in terms of the 'rhythm' in electronic configuration (2:8:8:18:18:32:32), which so aptly explains how the elements cluster into blocks - 's', 'p', 'd', and 'f'. It is important now to emphasise that the most important elements - the elements of life - C, H, N, P, O and S - are in the p block, as are all the gaseous elements, except hydrogen. The most significant value of the periodic table is the prediction and rationalisation of the physical and chemical properties of the elements and their compounds based on their position in the table. In this context, it is appropriate to discuss the properties of Group XV111 the noble gases and the reason why the name of this group has been changed from 'inert' to 'noble' gases due to the discovery of compounds of these elements in the mid- 20<sup>th</sup> century.

Specific reference should be made to the elements of 'life' – carbon, nitrogen, oxygen, phosphorus and sulphur – since these are the constituents of proteins. Also, a brief discussion should be included of the natural nutrient cycles, particularly the carbon nutrient cycle. The latter can also be used as a template to explain the consequences of increased levels of carbon dioxide in the upper atmosphere.

#### BONDS

Chemical bonds lead to the formation of molecules. Atkins has proposed that 'sharing of electron pairs' is the core idea of molecular structure and that ionic bonding is the extreme kind of covalent bonding and that metallic bonding is a special type of ionic bonding. It is appropriate to discuss in the 'Chemistry Fundamentals' course some common and important ionic and covalent inorganic compounds together with a selection of organic compounds which show that these are characterised by their 'functional group'. Some examples of organic compounds of biological and environmental significance are worthy inclusions. The important interrelated concepts of 'bond length' and 'bond energy' should be included with reference to covalent bonds. Also, hydrogen bonds should be briefly discussed because of their significance in explaining the anomalous physical properties of water and the folding structures of proteins.

It is appropriate to discuss in this section the unique ability of C to form single, double and triple bonds with itself and to bond to hydrogen, oxygen and nitrogen to form an unlimited range and number of compounds, considered collectively as a separate branch of chemistry known as 'organic chemistry'. Also, it is noteworthy to mention that the main natural source of organic chemicals is 'coal'.

## SHAPE

Atkins has emphasised that 'shape' is 'function' in the biological world. However, shape not only relates to molecular architecture, but also to the shape of atoms – leading to the concept of ionic radius and its relationship to ionisation energy and electron affinity and hence, to electronegativity. Further, ionic radius has a major influence on ionic and covalent character of chemical bonds, such that shape determines 'polarity', which in turn influences the magnitude of inter-molecular interactions and solubility of compounds in water.

Since atoms and ions are considered to be spherical in shape, the structures of ionic compounds, such as sodium chloride, are best described in terms of the close packing of spheres with emphasis on the symmetry of the resulting structures. For covalent compounds, the basic principles of hybridisation and VSEPR theories are required to explain the structures of symmetrical molecules, such as methane and asymmetric structures such as water and ammonia. It is also important to relate polarity of molecules to their molecular structures. Further, discussion of the structures of diamond and graphite introduces the concepts of electrical and thermal conductivity and mechanical strength of materials, thus revealing that the properties of bulk matter are defined at the molecular level.

A brief mention of the presence of 'cavities' within structures is important in terms of explaining porosity and absorption properties of bulk materials and also catalytic activity.

#### **INTER-MOLECULAR FORCES**

Atkins has described bulk matter as aggregates of molecules formed by inter-molecular attractions. The most important consequence of inter-molecular forces is that the relative strengths of these distinguish the characteristics of gases from those of liquids and solids. The weakest inter-molecular forces are present in gases and the strongest are present in solids with liquids having inter-molecular forces of intermediate strength. Inter-molecular forces should be described in terms of the polarizability of molecules with special emphasis on hydrogen bonding, which explains the structure of ice, the high boiling point of water and its unique solvent property. Also, most significantly, hydrogen bonding plays a critical role in the structure of proteins and hence, in the 'molecules of life'.

Now follows discussion of the properties of gases (Gas laws, Graham's law), solids, liquids and solutions (Raoult's law, Henry's law, osmotic pressure). Special emphasis should be given to the solubility of carbon dioxide in water, since this is a critical stage of the natural carbon cycle and hence, of enormous significance in the present climate change debate.

## REACTIONS

Atkins has proposed that chemical reactions can be categorised into just four types: proton transfer (acid/base), electron transfer (redox), electron sharing (radical) and electron pair sharing (Lewis acid/base). Thus, by inference, all reactions involve electrons.

The 'Chemistry Fundamentals' course should therefore contain many examples of acid/base and redox reactions with, perhaps, a few examples of radical and Lewis acid/base reactions. The latter allows a wider, more general definition of acids and bases to be introduced and opens discussion of coordination chemistry and its importance in biochemistry. Of major importance is to show how chemical reactions are described by 'equations', which are different to mathematical equations and that when these are balanced, the stoichiometry of a reaction is defined in terms of the numbers of moles of reactants reacting and the numbers of moles of products formed. Reactions selected for discussion should include not only the common inorganic reactions, but also net ionic reactions, simple organic reactions and reactions of environmental significance, such as the solubility of carbon dioxide in water and the reaction of carbon dioxide with water to give carbohydrates and oxygen under the influence of sunlight and chlorophyll.

## ENERGY

Atkins has described 'energy' as 'transactions' associated with chemical reactions which are defined by the 'thermal accounting device' – 'enthalpy'. This is a tangible way of introducing the abstract concept of energy in the 'Chemistry Fundamentals' course – simply that energy 'lost' and 'gained' has to be 'accounted for' and the account must 'balance', which is effectively a simplified statement of the first law of thermodynamics. Indirectly, it is also a definition of state functions such as enthalpy and also a simplified statement of Hess's law.

Since the combustion of fossil fuels is expected to provide the bulk of global energy requirements for at least the next 50 years, a suitable introductory example of the application of the first law of thermodynamics is the 2 – stage combustion of carbon. Similarly, the energy release from typical fuels such as methane (compressed natural gas), propane (liquefied propane gas) and petrol (octane) further illustrate the contemporary dilemma that fossil fuels are not only the (global) primary energy resource but also, are the primary contributor to global warming.

It now needs to be emphasised that if a reaction is exothermic, it is not necessarily 'spontaneous' since the thermodynamic quantity that governs 'reaction spontaneity' is 'free energy' and not enthalpy. This effectively introduces discussion of the second law of thermodynamics.

The need to pursue and develop 'clean energy resources' should be discussed together with the

'advantages' and 'disadvantages' of these by comparison to 'coal' and 'oil' (Fig.4) in addition to exploring energy derived from biological systems.



# Figure 4. The quest for 'Clean Energy Resources'

The National Academy of Sciences (NAS) in the United States recommends that research at the intersection of physical and biological sciences is critical to finding solutions to pressing societal issues such as According to the NAS "of the clean energy [9]. opportunities at the intersection of the physical and biological sciences, perhaps none has such intriguing potential as understanding, controlling, and improving photosynthesis, with the goal of decoupling it from plants" (p. 27). This remains a challenge. "Biological systems generate their energy directly in mitochondria at efficiencies of near 90 percent. The energy chemistry in mitochondria is analogous to that in fuel cells, wherein hydrogen and oxygen in the presence of catalysts are converted to water while generating electricity" (p. 28). Chemists working with biologists are capable of finding lasting solutions that lie beyond the traditional boundaries of the chemical sciences.

## ENTROPY

Atkins has described 'entropy' as the natural (spontaneous) direction of change from 'order' to

'disorder'. Thus, a decrease in Gibbs free energy of a chemical reaction corresponds to an increase in entropy under constant temperature and pressure conditions. This is a simple explanation of the second law of thermodynamics and also explains why change in free energy and not enthalpy change defines reaction spontaneity. The concept of chemical equilibrium then follows as does the relationship between free energy change and equilibrium constant. Le Chatelier's principle further enhances understanding of chemical equilibrium, particularly with respect to its dependence on temperature. It is important to emphasise that from a chemistry perspective, free energy has greater significance than entropy, despite the latter being the more fundamental thermodynamic quantity.

Since it is widely known that students dislike 'thermodynamics' because of its abstract connotations and mathematical complexity, it is appropriate to show them ways in which nature uses thermodynamics most effectively – as for example in the growth of calcium carbonate structures such as 'shells' and 'bones'. Essentially, the 'local environment' is 'manipulated' by the organism such that the balance between 'enthalpy' and 'entropy' is negative thereby ensuring that development of such structures is spontaneous. The principle of controlling the local environment thermodynamically is the basis of crystal tectonics or 'crystal engineering' whereby crystalline materials are formed under carefully controlled conditions with predetermined physical properties.

## **KINETICS**

Although thermodynamics indicates whether a chemical reaction is spontaneous, it does not reveal the rate at which reactants convert to products. This is the domain of chemical kinetics. In this context, it is noteworthy that biochemical reactions - the life sustaining processes - are kinetically 'slow' whether in 'forming' or 'decaying'. An important initial concept is that for reactions that have attained equilibrium, this means that the rates of the 'forward' and 'reverse' reactions are the same. The central concept to include in the 'Chemical Fundamentals' course is that 'energy barriers' are associated with all chemical reactions, which must be overcome for reactions to proceed. The concept of 'activation energy' follows in conjunction with the relationship between reaction rate and temperature (Arrhenius equation). The critical role of catalysts and the biological counterparts – enzymes in reducing activation energy should be emphasised with special reference to 'molecular shape' in explaining how catalysts function in conjunction with the concept of catalysts 'anchoring' molecules on their surfaces such that the reaction of interest is initiated with reduction of activation energy.

A contemporary example, that of radioactive decay, adequately introduces the concepts of reaction rate, reaction order and half-life, and emphasises the importance of radiocarbon dating and the advantages and disadvantages of nuclear energy.

#### **MODULE STRUCTURE**

This course can easily be divided into modules with a 'prologue module' outlining the breadth and depth of chemistry and its central role as an 'enabling science' and an 'epilogue module' outlining the benefits of chemistry to understanding how the world functions, how it benefits humanity and how it contributes to the sustainability of the environment. (These two modules are not assessed.) To illustrate the modular structure of this course, the composition of a proposed 'Intermolecular Forces' module is shown here.

#### **INTER-MOLECULAR FORCES**

#### LEARNING OBJECTIVES

To understand how inter-molecular forces influence the physical properties of liquids and solids.

#### REVIEW

There are three types of inter-molecular forces: 'dispersion', 'dipolar' and 'hydrogen bonding'. Dispersion forces (induced dipole forces) are the attractions between 'electron clouds' of a molecule and the positively charged nuclei of neighbouring molecules. Dipolar forces are the attractive forces between polar molecules. 'Hydrogen bonding' is a special type of dipolar forces and it can be both inter- and intramolecular in character. Inter-molecular forces are weak compared to the strengths of covalent and ionic bonds, but are greatest for solids and least for gases and of intermediate strength for liquids. The strengths of chemical bonds determine the chemical properties of compounds, but the strengths of inter-molecular forces determine the physical properties of compounds.

Fundamentally, the inter-molecular forces influence the closeness of packing of molecules in gases, liquids and solids. Solids are highly close packed whereas for gases, the molecules are randomly distributed and liquids are less closely packed than solids. Thus, gases can easily be compressed by applying pressure, whereas liquids and solids are incompressible. Effusion and diffusion are rapid for gases, but slow for liquids and non-existent for solids.

Viscosity, surface tension and evaporation rate are important physical properties of liquids. Viscosity is the flow characteristic of liquids. The greater the intermolecular forces, the greater the resistance of a liquid to flow and hence, the greater is its viscosity. A liquid has surface tension due to inter-molecular forces being greater in the bulk than at the surface. Surface tension increases as inter-molecular forces in a liquid increase. Evaporation rate relates to the conversion of a liquid to gas. As inter-molecular forces increase, evaporation rate decreases. Increasing temperature increases evaporation rate. Once the vapour pressure of a liquid is equivalent to the atmospheric pressure, it boils and the temperature at which this occurs is the normal boiling point of the liquid.

It is important to relate inter-molecular forces to molecular structure so as to be able to rationalise the physical properties of liquids and solids. Dipolar forces in general and hydrogen bonding in particular are the primary factors influencing the physical properties of liquids.

#### WORKED EXAMPLE 1

Which has the greater viscosity and the greater surface tension – ethylene glycol or ethanol?

The structural formula of ethylene glycol is  $HO - CH_2CH_2 - OH$ , and that of ethanol is  $CH_3CH_2OH$ .

Ethylene glycol has two terminal OH groups, whereas ethanol only has one; so the inter-molecular forces are greater for ethylene glycol and hence, it has the greater viscosity and the greater surface tension.

#### WORKED EXAMPLE 2

For the following pairs of liquids, which has the greater evaporation rate at 298 K?

- (a)  $CH_3CH_2CH_3$  or  $CH_3CH_2CH_2CH_2CH_3$
- (b) CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>OH or CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub>

- (a) Neither propane nor pentane is polar and so only dispersion forces prevail. These are greater for pentane than for propane since the probability for induced dipole formation increases with carbon chain length; so the intermolecular forces are greater for pentane and its evaporation rate is greater than that of propane.
- (b) Butanol has a terminal OH group which leads to hydrogen bonding, and diethylether is polar due to its bent structure. However, intermolecular hydrogen bond strength is greater than that of dipole-dipole attractions, so diethylether has the greater evaporation rate.

#### WORKED EXAMPLE 3

Arrange the following liquids in order of increasing normal boiling point:

(a) (CH<sub>3</sub>)<sub>2</sub>CHNH<sub>2</sub> (b) (CH<sub>3</sub>)<sub>2</sub>CH<sub>2</sub> (c) (CH<sub>3</sub>)<sub>2</sub>CO

Compound (a) has H - N ---H hydrogen bonding: compound (b) has only dispersion forces since it is non-polar and compound (c) has dipolar forces since it has a C – O permanent dipole; so the order of increasing inter-molecular forces is (a) > (c) > (b) and hence, this is the order of increasing normal boiling point.

Note: Hydrogen bonding is of particular importance in understanding the structures and functions of proteins.

#### PRACTICE QUESTIONS

1. For the following pairs, which has the stronger inter-molecular attractions?

(a)  $PF_{3}$ ,  $PCl_{3}$  (b)  $CH_{4}$ ,  $SiH_{4}$  (c)  $CH_{4}$ ,  $CHCl_{3}$  (d) HF, HCl (e)  $Cl_{2}$ ,  $Br_{2}$  (f)  $C_{2}H_{6}$ ,  $C_{6}H_{14}$ .

[Hint: The order of increasing inter-molecular force strength is: Hydrogen Bonding > Dipole/Dipole > Induced Dipole/Induced Dipole.]

 $[\ (a)\ PF_3\ (b)\ SiH_4\ (c)\ CHCl_3\ (d)\ HF\ (e)\ Br_2\ (f) \\ C_6H_{14}]$ 

- 2. Arrange the following liquids in order of increasing strength of inter-molecular forces present and increasing order of evaporation rate and give reasons:
  - (a) (CH<sub>3</sub>)<sub>2</sub>CHOH (b) C<sub>3</sub>H<sub>8</sub> (c) CH<sub>3</sub>COCH<sub>3</sub>

[Inter-molecular forces order is a > c > b: (a) has hydrogen bonding: (b) has dipole/dipole interactions: (c) has only induced dipole interactions.]

3. The vapor pressures of the following organic solvents at 20°C are:

CS<sub>2</sub>, 294 torr: C<sub>2</sub>H<sub>5</sub>OH, 44 torr: CH<sub>3</sub>OH, 96 torr: (CH<sub>3</sub>)<sub>2</sub>CO, 186 torr.

Arrange these in increasing order of intermolecular forces operating and increasing order of evaporation rate.

[Hint: The greater the vapor pressure, the lesser are the intermolecular forces.]

 $[CS_2 < (CH_3)_2CO < CH_3OH < C_2H_5OH :$ Evaporation rate is the opposite sequence.]

4. Which has the higher normal boiling point ethylene glycol or ethanol and why?

[The inter-molecular forces are greater for ethylene glycol so it has the lower evaporation rate and hence the higher (normal) boiling point.]

It should be noted that the module structure adopted here follows 'best practice' recommendations, namely commencing with a concise brief overview of the title topic followed by 'worked examples' followed by 'practice exercises'. Answers to the latter are provided. It should also be noted that online structured learning programs could be used to animate modules and to guide and assist problem solving [10].

#### CONCLUSION

Atkins has shown that 'basic chemistry' can effectively be understood in terms of nine interrelated core concepts, with each given equal emphasis, such that chemistry is revealed as the 'central, enabling science'. However, the 'Chemistry Fundamentals' course should also emphasise that chemistry has 'social', 'environmental', 'economic' and 'ethical' responsibilities and accountabilities and therefore, has a critical role to play in the contemporary challenge of sustainable natural resource management (SNRM), which is inclusive not only of remediating climate change, but also of sustaining the environment for future generations. It is vitally important that the 'Chemistry Fundamentals' course not only discuss the fundamental concepts of chemistry, but also portray these in a sustainability context in line with contemporary pedagogy of embedding sustainability in tertiary curricula [11]. This has the added advantage of showing that chemistry is fulfilling its responsibilities to the chemical industry, the wider chemical enterprise, and society at large and to preservation of the environment. It also emphasises that chemical education is an enabling force in understanding and remediating climate change, and that chemistry 'solves' rather than 'creates' problems for humanity.

## **RECOMMENDED REFERENCE TEXT**

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