

National Science Olympiad

Past Examination Questions and Answers (2007): Chemistry Section



NATIONAL SCIENCE OLYMPIAD 2007: CHEMISTRY SECTION

The answers have been compiled from a variety of sources, mainly Wikipedia (the free online encyclopaedia), Encyclopaedia Britannica, the Kirk-Othmer Encyclopaedia of Chemical Technology and a variety of chemistry textbooks.

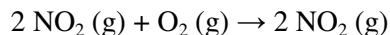
- (1) In the following list, _____ is not an example of matter.

- (a) planets
- (b) elemental phosphorus
- (c) table salt
- (d) light

Answer:

From the definition of matter (physical substance in general, anything that occupies space and possesses rest mass), **the only correct answer is (d).**

- (2) Given the general gas equation $pV = nRT$, calculate the volume (in dm^3) of O_2 at a pressure of 75 kPa and 20°C needed to form 5.00 dm^3 of NO_2 at 80 kPa and 15°C according to the equation:



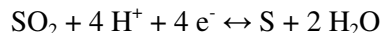
- (a) 1.76
- (b) 2.30
- (c) 4.61
- (d) 5.40

Answer:

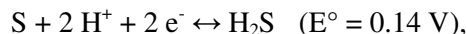
To form $5.00 \text{ dm}^3 \text{ NO}_2$ requires $2.50 \text{ dm}^3 \text{ O}_2$

$$\begin{aligned} V_2 &= (P_1 V_1 / T_1) \times (T_2 / P_2) \\ &= (75 \text{ kPa} \times 2.50 \text{ dm}^3 / 293 \text{ K}) \times (288 \text{ K} / 80 \text{ kPa}) \\ &= 2.30 \text{ dm}^3 \text{ [Option (b)]} \end{aligned}$$

- (3) If SO_2 as an oxidizing agent is to be placed on the list of standard reduction potentials, it would be written as:



If the following half-reaction is borne in mind:



choose a possible E° value for the SO_2 half-reaction from the following list:

- (a) 0.16 V
- (b) 0.08 V
- (c) -0.30 V
- (d) -0.70 V

Answer:

For the reaction $\text{SO}_2 + \text{H}_2\text{S} \rightarrow 2 \text{S} + 2 \text{H}_2\text{O}$,

$$E^\circ_{\text{cell}} = E^\circ_{\text{O.A.}} - E^\circ_{\text{R.A.}}$$

$$= E^\circ_{\text{S}/\text{SO}_2} - 0.14$$

The reaction is spontaneous, so $E^\circ_{\text{S}/\text{SO}_2} - 0.14 > 0$, therefore $E^\circ_{\text{S}/\text{SO}_2} > 0.14 \text{ V}$. Only **option (a)** is greater thus **correct**.

(4) All atoms of a given element have the same _____.

- (a) number of protons
- (b) number of neutrons
- (c) number of electrons and neutrons
- (d) mass

Answer:

All atoms of a given element have the same number of protons (atomic number). Variation in the number of neutrons gives rise to isotopes whilst variation in the number of electrons gives rise to ions (oxidation states). Thus, option **(a)** is **correct**.

(5) There are _____ electrons, _____ protons, and _____ neutrons in an atom of



- (a) 78, 78, 132
- (b) 78, 78, 54
- (c) 54, 54, 132
- (d) 54, 54, 78

Answer:

Subtracting the atomic number (no of protons) from the given mass number gives the number of neutrons:

$$132 - 54 = 78.$$

For a neutral atom, atomic number equals the number of electrons thus the **correct option is (d)**.

(6) The element X has three naturally occurring isotopes. The masses (amu) and % abundances of the isotopes are given in the table below.

Isotope	Abundance	Mass
^{221}X	74.22	220.9
^{220}X	12.78	220.0
^{218}X	13.00	218.1

The average atomic mass of the element is _____ amu.

- (a) 220.4
- (b) 219.7
- (c) 22042
- (d) 221.0

Answer:

To calculate the average mass of an atom of the element we simply multiply the fractional abundance of each isotope by its mass and then add the products:

$$(0.7422 \times 220.9) + (0.1278 \times 220.0) + (0.1300 \times 218.1) = 220.4. \text{ Thus, option (a) is the only one correct.}$$

- (7) The formula and name of the ester formed when ethanoic acid reacts with propanol are, respectively,

- (a) $\text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3$;
ethyl propanoate
(b) $\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3$;
propyl ethanoate
(c) $\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3$;
ethyl propanoate
(d) none of the above

Answer:

The name of an ester is always two words and is derived from the parent name of the alcohol with suffix *yl* followed by the parent name of the acid and ending with the suffix *ate*. Thus from propanol and ethanoic acid we get the ester propyl ethanoate [**option (b)**].

- (8) Which of the following are combination reactions?

- (1) $\text{CH}_4(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
(2) $\text{CaO}(\text{s}) + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s})$
(3) $\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{MgO}(\text{s})$
(4) $\text{PbCO}_3(\text{s}) \rightarrow \text{PbO}(\text{s}) + \text{CO}_2(\text{g})$

- (a) 1, 2, 3, and 4
(b) 4 only
(c) 2, 3, and 4
(d) 2 and 3

Answer:

As the name suggests, a combination reaction is simply one in which two or more reactants combine to form one product or a number of products fewer than the number of starting materials. Reaction equations 2 and 3 fit this criterion and thus **option (d)** is correct.

- (9) Which one of the following molecular formulas is also an empirical formula?

- (a) $\text{C}_6\text{H}_6\text{O}_2$
(b) C_6H_6
(c) $\text{H}_2\text{P}_4\text{O}_6$
(d) $\text{C}_2\text{H}_6\text{SO}$

Answer:

An empirical formula merely indicates the relative ratios of each kind of atom in a substance whilst a molecular formula gives the actual numbers of each kind of atom in a molecule. Options (a), (b) and (c) have the ratios that are all divisible by 2 and can thus not be empirical formulae. Thus, the only **correct option is (d)**.

- (10) Calculate the percentage by mass of nitrogen in $\text{PtCl}_2(\text{NH}_3)_2$.

- (a) 4.67
(b) 9.34
(c) 4.95
(d) 12.67

Answer:

Look up the molar masses of the elements in the Periodic Table. The percentage by mass of nitrogen is calculated as follows:

$$\frac{2 \times 14}{195.08 + (2 \times 25.45) + (2 \times 14) + (2 \times 3 \times 1.008)} \times 100$$
$$= 9.34\% \text{ [Option (b)]}$$

(11) The balanced reaction between aqueous nitric acid and aqueous strontium hydroxide is _____.

- (a) $\text{HNO}_3(\text{aq}) + \text{Sr}(\text{OH})_2(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{Sr}(\text{NO}_3)_2(\text{aq})$
- (b) $\text{HNO}_3(\text{aq}) + \text{SrOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{SrNO}_3(\text{aq})$
- (c) $2\text{HNO}_3(\text{aq}) + \text{Sr}(\text{OH})_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{Sr}(\text{NO}_3)_2(\text{aq})$
- (d) $2\text{HNO}_3(\text{aq}) + \text{Sr}(\text{OH})_2(\text{aq}) \rightarrow \text{Sr}(\text{NO}_3)_2(\text{aq}) + 2\text{H}_2(\text{g})$

Answer:

Strontium is in group two and its hydroxide, which is a base, has the formula $\text{Sr}(\text{OH})_2$. For complete neutralisation, it requires two moles of nitric acid (a monoprotic acid) to form a salt (strontium nitrate) and water. Thus, only **option (c) is correct**.

(12) Zinc is more active than cobalt and iron but less active than aluminium. Cobalt is more active than nickel but less active than iron. Which of the following correctly lists the elements in order of increasing activity?

- (a) $\text{Co} < \text{Ni} < \text{Fe} < \text{Zn} < \text{Al}$
- (b) $\text{Zn} < \text{Al} < \text{Co} < \text{Ni} < \text{Fe}$
- (c) $\text{Fe} < \text{Ni} < \text{Co} < \text{Al} < \text{Zn}$
- (d) $\text{Ni} < \text{Co} < \text{Fe} < \text{Zn} < \text{Al}$

Answer:

This is a question of simple logic and only **option (d) is correct**.

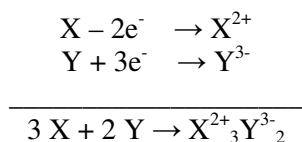
(13) Element X has 2 valence electrons, and element Y has 5 valence electrons. The most likely type and formula of the compound formed when X and Y combine chemically are

- (a) covalent, X_3Y_2
- (b) ionic, X_3Y_2
- (c) ionic, X_2Y_3
- (d) ionic, X_5Y_2

Answer:

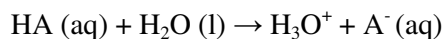
With two valence electrons (a group 2 element), element X will act as a reducing agent whilst Y, with 5 valence electrons (a group 5 element), will

act as an oxidizing agent and acquire three electrons to achieve an octet:



Thus, **option (b)** is the only one **correct**.

(14) The weak acid HA ionises in water as follows:



Given that the ionisation constant of HA is 4.50×10^{-4} , the pH of a 0.10 mol.dm^{-3} aqueous solution of HA is

- (a) 1.00
- (b) 2.17
- (c) 2.19
- (d) none of the above

Answer:

$$K_a = 4.50 \times 10^{-4} = \frac{[H_3O^+][A^-]}{[HA]} = \frac{[H_3O^+]^2}{[HA]}$$

Upon dissociation the concentrations of the ions will be:

$$[H_3O^+] = [A^-] = x \text{ and } [HA] = 0.10 - x$$

$$4.50 \times 10^{-4} = \frac{x^2}{(0.10 - x)}$$

$$x^2 + 4.50 \times 10^{-4}x - 4.50 \times 10^{-5} = 0$$

$$x = 6.49 \times 10^{-3}$$

$$\text{pH} = -\log(6.49 \times 10^{-3}) = 2.19$$

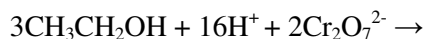
(15) Which of the following statements correctly describes what happens when potassium dichromate reacts with ethanol in an acid medium?

- 1. Ethanoic acid is formed
- 2. An ester is formed
- 3. The solution turns green
- 4. The ethanol is oxidized

- (a) 1, 3 and 4 only
- (b) 1 and 3 only
- (c) 2 only
- (d) 1 only.

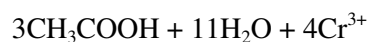
Answer:

The correct option is (a).



ethanol

orange



ethanoic acid

green

(16) Of the following statements, _____ is not true for oxygen.

- (a) Oxygen forms peroxide and superoxide anions
- (b) The most stable allotrope of oxygen is O_2
- (c) Oxygen is a colourless gas at room temperature
- (d) Dry air is about 79% oxygen

Answer:

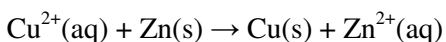
Oxygen has 2 allotropes (O_2 and ozone, O_3) the most stable of which is O_2 . It is a colourless gas that we breathe in all the time. It reacts to form oxides (O^{2-}), peroxides (O_2^{2-}) and superoxides (O_2^-) with other elements. Oxygen constitutes 21% of air. Thus, **option (d) is the correct answer.**

(17) When a Cu-Zn galvanic cell operates under standard conditions,

- (a) the concentration of Zn^{2+} ions in the zinc half-cell gradually decreases
- (b) the concentration of Cu^{2+} ions in the copper half-cell gradually increases
- (c) negative ions migrate from the zinc half-cell to the copper half-cell
- (d) the intensity of the colour of the electrolyte in the copper half-cell gradually decreases

Answer:

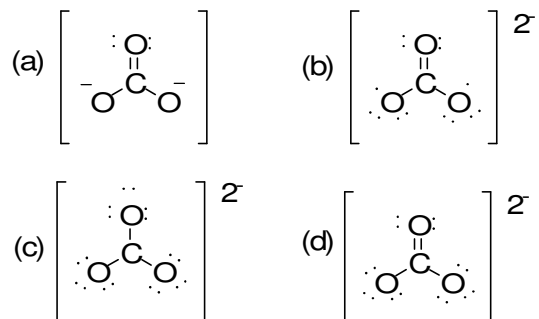
Copper will act as an oxidant and get reduced to the metal, whilst zinc metal will act as a reductant and get oxidised to solvated ions (see the standard reduction potentials table):



blue

As more of the copper salt is consumed, the intensity of the colour of the electrolyte in the copper half-cell gradually decreases [**Option (d)**].

(18) The Lewis structure of the CO_3^{2-} ion is _____.



Answer:

In drawing Lewis dot diagrams, we aim to achieve an octet for each atom. The electron (pairs) are represented as dots, and it is acceptable to show bonding electrons as lines (single for 2 electrons, denoting a single bond, and double lines for a double bond, representing 4 electrons). Note that non-bonding electrons (lone pairs) must be represented as dots only! The overall charge on the ion is then put as a superscript on square brackets to show delocalization. Alternatively, it can be distributed throughout the most electronegative atoms on the ions. Taking all these into account, only **option (d) is correct.**

(19) Which of the following, _____ is a greenhouse gas.

- (a) O_2
- (b) CH_4
- (c) C_2H_4
- (d) Xe

Answer:

Greenhouse gases are transparent to shortwave radiation from the sun, the main source of heat on earth. However, they absorb some of the longer infrared radiation emitted by the earth, thereby reducing radiational cooling and hence raising the temperature of the earth. This trapping of heat in the lower levels of the atmosphere is the so-called greenhouse effect. Next to water vapour, carbon dioxide is the most important gas in this process. There are other trace gases that, in concentration in the atmosphere, can create a strong greenhouse effect. Notable among these is methane (CH_4) [**Option (b)**], which is produced by insects, humans, and other animals, and nitrous oxide (N_2O), which may be increasing due to the rapid growth in the use of nitrogen fertilizers.

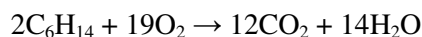
(20) The energy produced in the internal combustion engine of a car comes from the burning of alkanes (present in petrol) in oxygen (present in air).

The volume of oxygen required for the complete combustion of 4 moles of hexane at STP, given that 1 mol of gas has a volume of 22.4 dm^3 at STP, is

- (a) 89.6 dm^3
- (b) 44.8 dm^3
- (c) 851.2 dm^3
- (d) 1.7 dm^3

Answer:

Option (c) is correct. The balanced, total combustion equation for hexane is:



$$\begin{aligned} \text{Volume of } O_2 &= 4 \text{ mol } C_6H_{14} \times (19 \text{ mol } O_2 / 2 \text{ mol } C_6H_{14}) \times (22.4 \text{ dm}^3 / 1 \text{ mol } O_2) \\ &= 851.2 \text{ dm}^3 \end{aligned}$$

(21) In liquids, the attractive intermolecular forces are _____.

- (a) strong enough to hold molecules relatively close together
- (b) very weak compared with kinetic energies of the molecules
- (c) strong enough to keep the molecules confined to vibrating about their fixed lattice points
- (d) strong enough to hold molecules relatively close together but not strong enough to keep molecules from moving past each other.

Answer:

Option (d) is correct. The most obvious physical properties of a liquid are its retention of volume and its conformation to the shape of its container. These properties serve as convenient criteria for distinguishing the liquid state from the solid and gaseous states. Gases, for example, expand to fill their container so that the volume they occupy is the same as that of the container. Solids retain both their shape and volume when moved from one container to another. A liquid lacks both the strong spatial order of a solid, though it has the high density of solids, and the absence of order of a gas that results from the low density of gases—*i.e.*, gas molecules are relatively free of each other's influence.

In an ideal gas—where there are no forces between molecules and the volume of the molecules is negligible; the chance of encountering a second molecule when moving away from a central molecule is independent of position. In a solid, molecules are fixed at distances that correspond to the locations associated with the solid's crystal structure. Liquids possess neither the completely ordered structure of a solid crystal nor the complete randomness of an ideal gas. The structure in a liquid is intermediate to these two extremes—*i.e.*, the molecules in a liquid are free to move about,

but there is some order because they remain relatively close to one another.

(22) Of the compounds below, a 0.1 M aqueous solution of _____ will have the highest pH.

- (a) NH_4NO_3 , K_b of $\text{NH}_3 = 1.8 \times 10^{-5}$
- (b) KCN , K_a of $\text{HCN} = 4.0 \times 10^{-10}$
- (c) NaHS , K_b of $\text{HS}^- = 1.8 \times 10^{-7}$
- (d) NaClO , K_a of $\text{HClO} = 3.2 \times 10^{-8}$

Answer:

pH is defined as $-\log[\text{H}^+]$ and from the autoprotolysis of water

$$\text{pH} + \text{pOH} = 14$$

$$K_w = K_a \times K_b$$

Of the four options given, (a) can be rejected outright because ammonium nitrate, a product of a weak base (NH_3) and a strong acid (HNO_3) is a weakly acidic salt hence its pH will be low. Of the remaining three options, we have been given K_b of $\text{HS}^- = 1.8 \times 10^{-7}$. For direct comparison, we need to find K_a of its conjugate acid (H_2S):

$$K_a(\text{H}_2\text{S}) = 1 \times 10^{-14} / 1.8 \times 10^{-7} (\text{HS}^-) = 5.56 \times 10^{-8}$$

A strong acid ionizes completely in water and has a high K_a value. Of the three options, KCN , which gives rise to the weakest acid (the lowest K_a) upon dissolution, will have the highest pH (*i.e.*, higher $[\text{OH}^-]$). Thus **option (b) is correct.**

- (23) Borax is a hydrated compound with the following percentage composition:

12.04 % Na; 11.52 % B;

29.32 O; 47.12 % H₂O

From the given percentage composition the empirical formula of borax can be shown to be

- (a) NaB₂O₃·5H₂O
- (b) Na₂B₄O₇·10H₂O
- (c) NaB₂O₄·5H₂O
- (d) none of the above

Answer:

Option (b) is correct.

Na B O H₂O

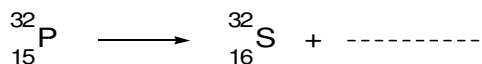
Mol: 12.04/23.0(Na) 11.52/10.8(B)
 29.32/16.0(O) 47.12/18.0(H₂O)
 = 0.523; 1.067; 1.832; 2.618

Mol ratio: 0.523/0.523; 1.067/0.523
 1.832/0.523 2.618/0.523
 = 1 : 2 : 3.5 : 5

Converting to whole numbers: 2:4:7:10.

Thus the formula is Na₂B₄O₇·10H₂O.

- (24) What is the missing product from this reaction?

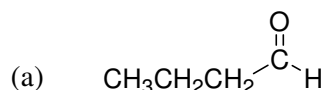


- (a) ${}^4_2\text{He}$ (b) ${}^1_1\text{e}$
- (c) ${}^0_1\text{e}$ (d) ${}^0_1\text{P}$

Answer:

The above equation shows a conversion of phosphorus to sulfur, with mass number (32) staying the same but the atomic number increased (from 15 to 16). This is only possible if a neutron (made up of an electron and a proton) is split and the number of protons increases (hence the change in atomic number) and an electron is liberated. This type of radioactive decay is called β⁻-decay and the **correct option is (c)**.

- (25) Which one of the following compounds is an isomer of CH₃CH₂CH₂CH₂OH?



- (b) $\text{CH}_3\text{CH}_2\overset{\text{OH}}{\underset{|}{\text{CH}}}\text{CH}_3$
- (c) CH₃OH
- (d) CH₃CH₂CH₂OH

Answer:

Isomers have the same the same chemical formula but different structures/spatial arrangement of atoms. Only **option (b) is correct**.

(26) John C. Mather, working for NASA, and George F. Smoot, working at the University of California, Berkeley, won the 2006 Nobel Prize in Physics for their discoveries supporting the big bang theory. What is the big bang theory?

- (a) the theory that God went “bang!” and the big universe was intelligently designed in six days
- (b) the theory that life on earth will one day end from a catastrophic collision of the planet with a huge asteroid
- (c) the theory that the universe began with the explosion of a primeval atom
- (d) the theory that the universe is the same at any point in time and new matter would be created as galaxies moved further apart.

Answer:

According to the **big-bang** model, the universe expanded rapidly from a highly compressed primordial state, which resulted in a significant decrease in density and temperature. Soon afterward, the dominance of matter over antimatter (as observed today) may have been established by processes that also predict proton decay. During this stage many types of elementary

particles may have been present. After a few seconds, the universe cooled enough to allow the formation of certain nuclei. The **theory** predicts that definite amounts of hydrogen, helium, and lithium were produced. Their abundances agree with what is observed today. About 1,000,000 years later the universe was sufficiently cool for atoms to form. The radiation that also filled the universe was then free to travel through space. This remnant of the early universe is the microwave background radiation (three degree background radiation) discovered in 1965 by Arno A. Penzias and Robert W. Wilson.

(27) Radicals such as nitric oxide, and halogens, lead to the depletion of ozone in the stratosphere. Which of the following represents the decomposition of ozone by any of these?

- (a) $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$
- (b) $\text{N}_2\text{O} + 3\text{O}_3 \rightarrow 2\text{NO}_2 + 3\text{O}_2$
- (c) $\text{HCl} + \text{O}_3 \rightarrow \text{HClO}_3$
- (d) $(\text{NH}_2)_2\text{CO} + \text{O}_3 \rightarrow \text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O}$

Answer:

The only **option** that has a halogen (radical) and shows decomposition of ozone is **(a)**. Note that no option contains nitric oxide (NO).

(28) In 1808 John Dalton published “*A New System of Chemical Philosophy*” detailing the atomic theory of matter. Which of the following statements is inconsistent with his atomic theory?

- (a) matter consists of indivisible atoms and all atoms of an element are identical in all respects
- (b) different chemical elements have different kinds of atoms and in particular, such atoms have different weights
- (c) atoms are indestructible and retain their identity in chemical reactions wherein they form compounds
- (d) atoms are destructible; some heavy ones break up to form lighter ones releasing energy and nuclear particles in a process called nuclear fission

Answer:

Option (d) is correct. The story of the discovery of nuclear fission began with the discovery of the neutron in 1932 by James Chadwick in England (long after Dalton’s death in 1844!). Shortly thereafter, Enrico Fermi and his associates in Italy undertook an extensive investigation of the nuclear reactions produced by the bombardment of various elements with this uncharged

particle. In particular, these workers observed (1934) that at least four different radioactive species resulted from the bombardment of uranium with slow neutrons. These newly discovered species emitted beta particles and were thought to be isotopes of unstable “trans-uranium elements” of atomic numbers 93, 94, and perhaps higher. There was, of course, intense interest in examining the properties of these elements, and many radiochemists participated in the studies. The results of these investigations, however, were extremely perplexing, and confusion persisted until 1939 when Otto Hahn and Fritz Strassmann in Germany, following a clue provided by Irène Joliot-Curie and Pavle Savic in France (1938), proved definitely that the so-called trans-uranium elements were in fact radioisotopes of barium, lanthanum, and other elements in the middle of the periodic table. It then became a major focus research aimed at producing a controllable nuclear chain reaction, which would mark the first harnessing of nuclear power. This led to the development of Chicago Pile-1, the world’s first man-made critical nuclear reactor (which used uranium, the only natural nuclear fuel available in macroscopic quantities), and then to the Manhattan project to develop a nuclear weapon.

(29) The order of filling electrons in shells of an element or its ions follows Pauli Exclusion Principle as well as Hund’s rule. Which one of the following electron configurations is inconsistent with the above?

- (a) $1s^2 2s^2 2p^3 3s^1$
- (b) $[\text{Ar}] 3d^6 4s^2$
- (c) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$
- (d) $[\text{Ar}] 3d^{10} 4s^2 4p^1$

Answer:

Option (a) is the answer sought. It shows the ground state electron configuration of oxygen; electrons cannot begin to fill the 3s orbital until the 2p orbital is completely filled!

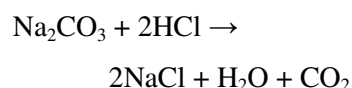
(30) Carbon, as diamond, has one of the highest melting points and is thus far, the hardest material known to man. However, some diamonds are not perfect and thus not as hard. The reason for this is that

- (a) some diamonds show multiple crystal growth stages which produce inclusions of other elements thereby introducing defects
- (b) errors occur during diamond cutting and polishing by inexperienced workers
- (c) some diamonds get soaked in blood during smuggling (Africa's "blood diamonds") which reduces hardness
- (d) none of the above

Answer:

The **correct option is (a)**. The hardest diamonds are single crystals which grow in one stage. Multiple growth stages allow for inclusion in the crystal lattice, of other elements, most notably nitrogen, which leads to crystal defects and negatively affects hardness. The way a diamond is cut and polished, only affects its optical properties. They must be cut and polished to exhibit the characteristic fire and brilliance that diamond gemstones are known for. Diamonds are cut into a variety of shapes that are generally designed to accentuate these features.

(31) 2.12 grams of anhydrous sodium carbonate are dissolved in 200 cm³ water. 25 cm³ of this solution neutralize 80 cm³ of a hydrochloric acid solution.



The concentration of the hydrochloric acid (in mol.dm⁻³) is

- (a) 0.03125
- (b) 0.0156
- (c) 1.325
- (d) 0.0625

Answer:

The concentration of base (sodium carbonate) is

$$C_b = 2.12 \text{ g} / (106 \text{ g.mol}^{-1} \times 0.2 \text{ dm}^3) = 0.1 \text{ mol.dm}^{-3}$$

From the reaction equation, the mole ratio of base to acid is:

$$C_a V_a / C_b V_b = 2/1$$

In the 25 mL of the base solution used for neutralization, there were:

$$0.1 \text{ mol.dm}^{-3} \times 25/1000 \text{ dm}^3 = 2.5 \times 10^{-3} \text{ moles of sodium carbonate.}$$

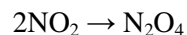
Thus, there were twice as many HCl moles as these no of moles of sodium carbonate in the 80 cm³ neutralized. The concentration of HCl is thus:

$$\begin{aligned} C_a &= (2/1) \times (C_b V_b / V_a) \\ &= (2/1) \times (0.1 \text{ mol.dm}^{-3} \times 25 \text{ cm}^3 / 80 \text{ cm}^3) \\ &= 0.0625 \text{ mol.dm}^{-3} \end{aligned}$$

- (32) At low temperatures, each gas in an all gas mixture independently obeys the ideal gas law. The mole fraction of any gas in the mixture (χ_i) is its number of moles divided by the sum of moles of all the gases in the mixture. Use this information to answer the following question.

When NO₂ is cooled to room temperature, some of it reacts to

form a dimer N₂O₄ according to the equation



Suppose 15.2 g of NO₂ is placed in a 10.0 litre flask at high temperature and the flask is cooled to 25 °C. The total pressure is measured to be 0.500 atmospheres. What are the partial pressures (P_i) and mole fractions of NO₂ and N₂O₄ present?

	NO ₂	NO ₂	N ₂ O ₄	N ₂ O ₄
	χ	P	χ	P
(a)	0.38	0.19 atm	0.62	0.31 atm
(b)	0.38	0.62 atm	0.62	0.19 atm
(c)	0.62	0.19 atm	0.38	0.31 atm
(d)	0.62	0.31 atm	0.38	0.19 atm

Answer:

Initially, there are $15.2 \text{ g} / 46.0 \text{ g.mol}^{-1} = 0.33 \text{ mol}$ NO₂ present and thus the same number of moles of nitrogen atoms. If at 25 °C there are x moles of NO₂ and y moles of N₂O₄, then, because the total number of moles of nitrogen atoms is unchanged:

$$x + 2y = 0.330 \text{ mol} \quad (1)$$

From Dalton's law:

$$P_{\text{NO}_2} + P_{\text{N}_2\text{O}_4} = 0.500 \text{ atm}$$

$$\text{Since } PV = nRT$$

$$\text{Total number of moles} = n = x + y = PV/RT$$

$$\frac{(0.500 \text{ atm})(10.0 \text{ L})}{(0.08206 \text{ L.atm.mol}^{-1} \cdot \text{K}^{-1})(298 \text{ K})}$$

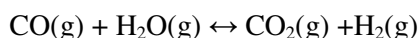
$$x + y = 0.204 \text{ mol} \quad (2)$$

Subtracting equation (2) from equation (1) gives:

$$x = 0.078 \text{ mol and } y = 0.126 \text{ mol}$$

Thus, NO_2 has mole fraction (χ) of 0.38 and partial pressure (P) $0.38 \times 0.500 \text{ atm} = 0.19 \text{ atm}$ and N_2O_4 has $\chi = 0.62$ and $P = 0.62 \times 0.500 = 0.31 \text{ atm}$.

- (33) An important step in the industrial production of hydrogen gas is the water-gas shift reaction. Used extensively at SASOL, the reaction entails heating carbon monoxide and water



At 500°C the equilibrium constant for this reaction is 3.9. If the equilibrium partial pressures of CO and H_2O are both 0.10 atm and that of CO_2 is 0.70 atm, the partial pressure of $\text{H}_2\text{(g)}$ will be

- (a) 3.9 atm
- (b) 0.70 atm
- (c) 0.056 atm
- (d) 0.10 atm.

Answer:

The equilibrium constant is related to the partial pressures of the individual gases according to the equation:

$$K = \frac{P_{\text{CO}_2} \times P_{\text{H}_2}}{P_{\text{CO}} \times P_{\text{H}_2\text{O}}}$$

Substituting the given values and solving for the unknown:

$$3.9 = \frac{0.7 \times P_{\text{H}_2}}{0.1 \times 0.1}$$

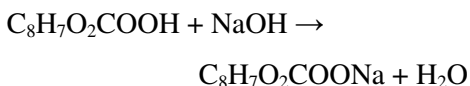
$$P_{\text{H}_2} = 0.056 \text{ atm}$$

- (34) Acetylsalicylic acid, commonly known as aspirin, is a weak acid (chemical formula $\text{C}_8\text{H}_7\text{O}_2\text{COOH}$) with acid dissociation constant $K_a = 3.4 \times 10^{-4}$. A tablet containing 5.0 milligrams of aspirin in a non-ionizing “binder” is dissolved in 100 mL of water. How many millilitres of a 0.0010 M NaOH solution are needed to achieve complete neutralization?

- (a) 100
- (b) 27.8
- (c) 14.5
- (d) 58.0

Answer:

Aspirin is a monoprotic acid and thus the neutralization reaction will proceed according to the equation:



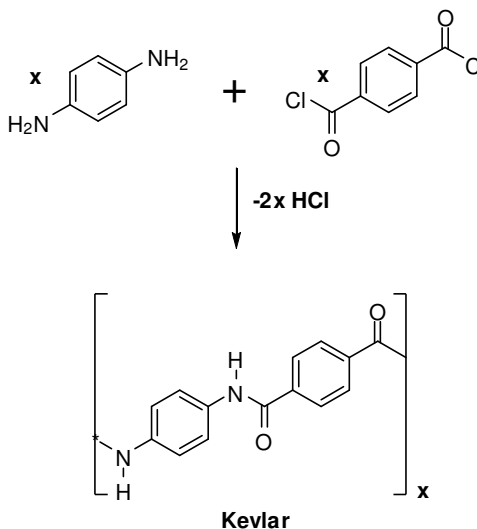
The molar mass of aspirin is $180.154 \text{ g}\cdot\text{mol}^{-1}$

Thus 5.0 milligrams equals

$$0.005 \text{ g} / 180.154 \text{ g}\cdot\text{mol}^{-1} = 0.000027754 \text{ moles}$$

Since the reaction stoichiometry is one to one, we need the same number of mole of NaOH for neutralization. By definition, a 0.0010 M NaOH solution contains 0.0010 moles per liter (1000 mL). A volume of this solution that will contain 0.000027754 moles is 27.8 mL.

(35) Kevlar is a light but very strong polymer developed by DuPont. It is prepared according to the equation



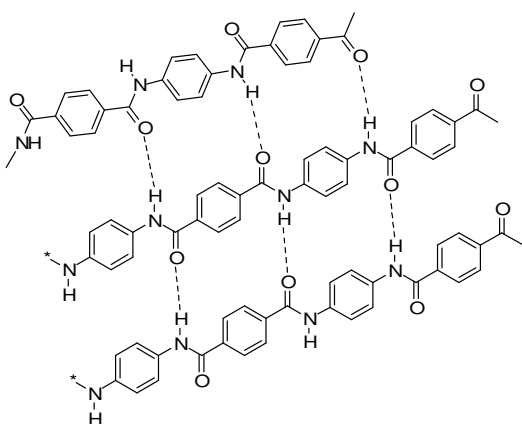
For its strength, Kevlar is used in reinforcing tyres, making bullet-proof vests and manufacturing cables, amongst others. From the depicted structure of Kevlar, its strength is due to:

- (a) extensive hydrogen bonding and good alignment of benzene rings (π stacking)
- (b) cumulative effects of weak Van der Waals' interactions, which is common in all polymeric materials
- (c) benzene rings acting as holes through which Kevlar strands intertwine, greatly enhancing its strength
- (d) none of the above; Kevlar is in fact not strong and cables are made of metals whilst bullet-proof vests contain lightweight metal alloys under a thick cotton wool pad

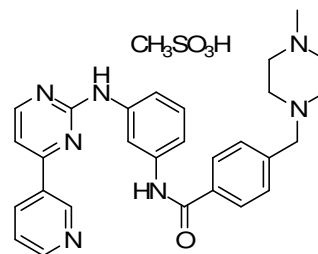
Answer:

The correct option is (a).

The amide linkages (HNC=O) of Kevlar strands allow for extensive hydrogen bonding (between the hydrogen bonded to nitrogen and oxygen on another strand). This aligns the strands and alignment of the hydrophobic benzene rings also contributes to the overall packing. Both of these are the reasons for the observed strength of Kevlar. Diagrammatically, these are shown below



- (36) Gleevec (see structure below) is an anti-cancer drug developed by the pharmaceutical company Novartis. It was approved by the US Food and Drug Administration (FDA) in 2003 for the treatment of chronic myeloid leukaemia. The functional groups present in Gleevec are:



- (a) benzene ring, amino group, amide group, sulfonic acid group, heterocycle
- (b) benzene ring, alcohol group, ester group, alkyl group, sulfonamide group
- (c) benzene ring, amino group, alkyne group, sulfonic acid group, ketone
- (d) amino group, benzene ring, alkyl group, amide group, carboxylic acid group

Answer:

A ring that contains as part of it, an atom other than carbon is called a heterocycle. There are three of these in Gleevec, in addition to two benzene rings. There are also three amino groups (nitrogens bonded to a hydrogen and/or carbon fragments), an amide bond and additionally, as a counter ion to one of the amino groups, a methanesulfonic acid group. Thus, the **correct option is (a)**.

- (37) In the period October 2004 to October 2006, the South African newspaper group, The Independent, published over 30 articles on viox. Viox (also called Rofexicob) was the drug manufactured by Merck and approved by the FDA as a non-steroidal anti-inflammatory drug to

treat arthritis. The drug was withdrawn on September 30, 2004, leading to several lawsuits against Merck. The reason for the drug's withdrawal was:

- (a) vioxx was not particularly effective and fared much worse than aspirin
- (b) Merck falsified clinical data and misled the FDA into approving vioxx
- (c) vioxx increased patients' risks of getting heart attacks
- (d) vioxx was too expensive to make and very little profit could be made from its sales, greatly upsetting Merck's shareholders

Answer:

Option (c) is correct. Read the article below from www.iol.co.za

Arthritis drug withdrawn after global alert

By Helen Bamford, October 02 2004 at 10:48am
An arthritis drug used by millions of people around the world, including many South Africans, has been hurriedly removed from pharmacies after tests found it could cause heart attacks and strokes. Tests in the United States found that patients who used the drug for more than 18 months were up to three or four times more likely to have heart attacks

or strokes. The drug, Vioxx, was voluntarily withdrawn worldwide by pharmaceutical giant Merck & Company this week, based on the results of a three-year clinical trial. The drug was launched in 1999, has been marketed in more than 80 countries and used by 84 million people around the world. Last year, worldwide sales netted \$2,5-billion and its withdrawal has sent the company's shares plummeting almost 27 percent and wiped \$25-billion off its market value. Patients taking Vioxx have been advised to stop immediately and consult their doctors about alternatives. South African Medicines Controls Council Chief Precious Matsoso said there would be an immediate global withdrawal of Vioxx.

This article was originally published on page 1 of *The Independent on Saturday* on October 02, 2004

- (38) Except for hydrofluoric acid, hydrogen halides are exceptionally strong acids as shown by the K_a values below.

Halide	K_a
HF	3.20
HCl	10^7
HBr	10^9
HI	10^{11}

The reason why HF is a weak acid is because _____

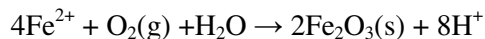
- (a) HF is a gas that is not very water-soluble and bubbles out
- (b) HF is very reactive and will corrode any container before it totally ionizes, making accurate K_a determination impossible
- (c) the ions formed upon dissociation are tightly held by hydrogen bonding and further bind HF, retarding its further ionization
- (d) like many compounds of fluorine, HF is a water-insoluble solid

Answer:

Option (c) is correct. The weakness of HF as an acid is due to extensive hydrogen bonding between the acid and water molecules. Hydrogen bonding occurs with only the most electronegative ions: fluorine, oxygen and nitrogen. The ions H_3O^+ and F^- that are formed by the ionization of HF in water are held together by a strong hydrogen bond $\text{F}^-\cdots\text{H}_3\text{O}^+$, and this hydrogen-bonded complex is incompletely dissociated to free H_3O^+ and F^- ions. Another complication is that HF also forms a hydrogen-bonded complex with F^- so that not all HF reacts with water to form H_3O^+ .

- (39) Corrosion is the deterioration of metals as a result of their reactions with the environment. Rusting of iron, for instance, is an

electrochemical process occurring according to the equations:



Which one of the following statements about the corrosion of iron is not true?

- (a) the iron in one part of the object acts as an anode where iron is oxidized
- (b) another part of the iron object acts as a cathode where oxygen is reduced to water
- (c) the rust thus formed is brittle and flakes off, exposing the metal to further attack
- (d) painting, galvanization, and cathodic protection do not work because iron is just too rust-prone

Answer:

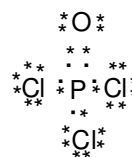
All the statements except (d) are true. The most obvious way of minimizing corrosion is to cover the metal surface with a coating that keeps out air and moisture. This coating can be provided in several ways. Steel used in bridges and buildings is often painted with red lead paint, which contains Pb_3O_4 . The Pb_3O_4 apparently oxidises the surface of the iron to form a tough continuous layer of the oxide, which resists further oxidation. Another method of protecting iron is to coat it with a layer of another metal. Zinc, tin and chromium are often used for this purpose. The use of a zinc coating to protect iron is called

galvanizing. Since zinc is below iron in the table of reduction potentials, it is more easily oxidized. Zinc is oxidized to Zn(OH)_2 , which reacts with atmospheric CO_2 to form a tough layer of $\text{Zn(OH)}_2 \cdot x\text{ZnCO}_3$, which strongly adheres to the surface, protecting the metal beneath. Even if the zinc layer is cracked or broken, it continues to protect the iron as it becomes the anode in a cell in which the iron is the cathode. A layer of tin, which becomes coated with a layer of oxide, can also be used to protect iron, as for example in tin cans. Tin comes above iron in the table of standard reduction potentials and is therefore less easily oxidized. But if the tin coating is cracked or scratched, the tin becomes the cathode in a cell and the iron becomes the anode. The oxidation of iron will then be speeded up.

Iron corrodes by becoming the anode in an electrochemical cell. However, if it is connected to a more easily oxidized metal such as zinc or magnesium, then this metal becomes the anode and gets corroded instead. The iron becomes the cathode at which oxygen is reduced to water. This method of preventing corrosion is called cathodic protection. The more easily oxidized metal is called a sacrificial anode. For example, if a magnesium or zinc rod is connected to an underground tank or steel pipe, then the magnesium or zinc is oxidized instead of the pipe. Although it is gradually

dissolved, it is easier to replace than the steel pipe or tank. This method also provides excellent protection for bridge foundations and steel ships.

- (40) The following Lewis dot diagram of phosphorus oxychloride is not entirely correct because



- (a) phosphorus has 10 electrons around it which violates the octet rule
- (b) as drawn, it is difficult to predict the shape of the molecule
- (c) oxygen, being the most electronegative, must have most of the electron density around it
- (d) all electrons, irrespective of source element, are identical and must thus be represented with dots or asterisks, not both

Answer:

Option (d) is correct. Only period 2 elements strictly obey the octet rule; others can accommodate many more electrons (period 3 and heavier) in their valence shells. Thus, option (a) is incorrect. Option (b) is also incorrect; the shape of the molecule is easy to tell, there are no lone pairs around phosphorus, the central atom, and it is

bonded to four other atoms, giving the molecule a tetrahedral shape. Option (c) is also incorrect; in drawing Lewis dot diagrams, polar covalent bonds (such as those between phosphorus and oxygen) are not normally shown as such.

(41) Before Neil Bartlett's experiment in 1962, group 18 elements were thought of as completely inert because of their fully occupied valence shells. A limited number of noble gas fluorides such as KrF_2 and oxides such as XeO_3 are now known. The reason why only oxygen and fluorine can react with only the heavier noble gases is because

- (a) oxygen and fluorine are powerful oxidants and will attack almost anything
- (b)** only oxygen and fluorine are electronegative enough to disrupt the completely paired Xe and Kr valence electrons and promote some to vacant d orbitals for bonding
- (c) noble gases are mildly reducing and can combine with sufficiently strong oxidizing agents
- (d) none of the above

Answer:

Only **option (b) is correct**. Since the valence shells of helium and neon are completely filled with two and eight electrons respectively, we do not expect to find any compounds of these two elements. However, argon, krypton, xenon and radon can all have more than eight electrons in their valence shells and they could in principle, form compounds. Argon compounds are however, not known and those of radon are difficult to study because of radon's radioactivity. However, a fluoride of krypton (KrF_2) and fluorides (XeF_2 , XeF_4 and XeF_6) and oxides (XeO_3 , XeO_4) of xenon are now known. Noble gases in their ground states do not have any unpaired electrons. Consequently, they can form compounds only via a valence state in which one or more s or p electrons is promoted to an unoccupied d orbital. Only the most electronegative elements, in particular, fluorine and oxygen-, exert sufficient attraction on the valence shell electrons to move some of them into the d orbitals.

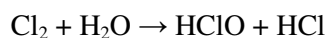
(42) Chlorine is often added as the last step in municipal water treatment. The reason for chlorine use is;

- (a)** in water, chlorine forms HCl , a strong acid; and HOCl , an oxidizing agent, both of which kill pathogens
- (b) as a toxic gas used in World War I, chlorine's presence deters theft and

- vandalism of municipal water infrastructure
- (c) chlorine is a reducing agent and helps precipitate undesirable heavy metals out of drinking water
 - (d) chlorine promotes the growth of fungi that produce antibiotics and help sanitize the water

Answer:

Chlorination is the process of adding the element chlorine to water as a method of water purification to make it fit for human consumption as drinking water. Water which has been treated with chlorine is effective in preventing the spread of disease. The use of chlorine has greatly reduced the prevalence of waterborne disease as it is effective against almost all bacteria and viruses. Chlorination is also used to sterilize the water in swimming pools and as a disinfection stage in sewage treatment. When chlorine is added to water, hypochlorous and hydrochloric acids form, an oxidizing agent and a strong acid, respectively:



Thus, **option (a) is correct.**

- (43) Fires are classified according to the burning material (fuel) and accordingly, there are various fire

extinguishers designed for each class of fire. For example, water is used to extinguish class A fires, which are burning wood, paper and other common combustibles. Fires due to metals (class D fires) are the most difficult to extinguish. Which of the following statement is not entirely correct?

- (a) water cannot be used on alkali metal fires because they break water down to hydrogen, which is flammable and explosive
- (b) carbon dioxide cannot be used on alkali metal fires because they continue to burn and produce toxic carbon monoxide
- (c) halogenated flame extinguishers cannot be used in metal fires because they break down to toxic phosgene and explosive fluorophosgene
- (d) rain extinguishes huge forest fires whilst oceans cool mighty volcanoes thus there is no reason why water cannot be used in any type of fire

Answer:

Option (d) is the answer. Class-A fires are the most common type of fire, which occurs when a material such as wood becomes sufficiently hot, and has oxygen available to it, causing combustion. At this point the material bursts into flame, and will continue burning as long as the fire triangle (heat, fuel, and oxygen) continues to be available to it. Class-A fires are used all around

buildings and everywhere in the world under controlled circumstances, such as a campfire, lighter, match, or candle. Class-A fires are fairly simple to fight and contain - by simply removing the heat or oxygen (or in some cases fuel), the fire triangle collapses and the fire dies out. The most common way to do this is by removing the heat by spraying the fire with water. Other means of control or containment would be to "smother" the fire with carbon dioxide or nitrogen from a fire extinguisher, cutting off its oxygen and causing the fire to die.

Class-B fires are combustible fuels, hydrocarbons or solvents on fire. These fires follow the same basic fire triangle (heat, fuel, and oxygen) as class-A fires, except that the fuel in question is a hydrocarbon or solvent. This changes the strategy that must be used when fighting them considerably. One method would be dropping or spraying a chemical retardant, such as *slurry*, onto the fire. This is usually done by plane, and the pumps required to handle a chemical retardant would not often be available to ground fire crews; this makes its use against class-B fires limited. A carbon dioxide fire extinguisher may be used on small class-B fires, though some fire extinguishers are not designed to fight against all classes of fire. The most common method for fighting class-B fires would be to use a type of

protein-based foam to cut off the fire's oxygen and cool the hydrocarbon/solvent.

Class-C fires are electrical fires, where the heat side of the fire triangle is caused by, for example, short-circuiting machinery or overloaded electrical outlets. These fires can be a severe hazard to firefighters using water: when the solid stream of water hits the electrical fire, the electricity is conducted through it and into the hose, then into the firefighter's body. Electrical shocks have caused many firefighter deaths.

There are two main ways of fighting a class-C fire: cutting off its oxygen, or simply turning off the electricity to the fire from a breaker. A class-C fire can be put out with a fire extinguisher rated for class-C fires, or with protein foam, but the primary approach is to simply turn off the power. This causes the fire to become an ordinary class-A fire, or perhaps to die out entirely.

Class-D fires are metal fires. Certain metals, such as sodium, titanium, magnesium, potassium, uranium, lithium, plutonium, calcium and others are flammable. Magnesium and titanium fires are common. When one of these combustible metals ignites, it can easily and rapidly spread to surrounding class-A materials.

Generally, masses of combustible metals do not represent unusual fire risks because they have the ability to conduct heat away from hot spots so efficiently that the heat of combustion cannot be maintained - this means that it will require a lot of

heat to ignite a mass of combustible metal. Generally, metal fire risks exist when sawdust, machine shavings and other metal 'fines' are present. Generally, these fines can be ignited by the same types of ignition sources that would start other common fires.

Water and other common firefighting materials can excite metal fires and make them worse. The NFPA recommends that class D fires be fought with 'dry powder' extinguishing agents. Dry Powder agents work by smothering and heat absorption. The most common of these agents are sodium chloride granules and graphite powder. In recent years powdered copper has also come into use. Some extinguishers use *dry chemical* extinguishing agents. This is easily confusable with *dry powder*. They are quite different, and using one of these extinguishers in error in place of dry powder can actually increase the size of a class D fire much like water. Class-D fires represent a unique hazard because people are often not aware of the characteristics of these fires and are not properly prepared to fight them.

(44) Water has rather anomalous properties when compared to hydrogen compounds of other chalcogens and to other liquids in general. Interestingly, these anomalies are the very reason why water is suited as a habitat and solvent for life's biochemical

processes. Some of these anomalies are tabulated below.

Property	Comparison with other substances
density	maximum at 4 °C, not at m.p.; expands upon freezing
m.p. and b.p.	abnormally high compared to other chalcogens hydrides
heat capacity	highest of any liquid except ammonia
absorption of radiation	large in infrared and ultraviolet regions; less in visible regions

These anomalies in water's properties can be attributed to:

- (a) the angular shape of water molecules, which allows for large flexibility
- (b) the small size of water molecules, allowing for compaction and permeation
- (c) the polarity of water molecules and the attendant strong hydrogen bond donor and acceptor capabilities
- (d) the subatomic nature of the molecules, which can be explained by quantum mechanical calculations

Answer:

Option (c) is correct. Water is a polar molecule with strong hydrogen bonding capability, with each molecule able to form four hydrogen bonds. This is the main reason why it shows these anomalies.

- (45) Albert Einstein is often regarded as the greatest scientist of the 20th century. He was awarded the 1921 Nobel Prize_____
- (a) in Physics for his theory of relativity
 - (b) in Chemistry, for explaining Brownian motion
 - (c) in Physics, for explaining the photoelectric effect
 - (d) for Peace, in recognition of his nuclear disarmament campaign

Answer:

Option (c) is correct. The following comes from the Nobel Foundation website (www.nobelprize.org)

The Nobel Prize in Physics 1921

Presentation Speech by Professor S. Arrhenius, Chairman of the Nobel Committee for Physics of the Royal Swedish Academy of Sciences, on December 10, 1922*

Your Majesty, Your Royal Highnesses, Ladies and Gentlemen. There is probably no physicist living today whose name has become so widely known as that of Albert Einstein. Most discussion centres on his theory of relativity. This pertains essentially to epistemology and has therefore been the subject of lively debate in philosophical

circles. It will be no secret that the famous philosopher Bergson in Paris has challenged this theory, while other philosophers have acclaimed it wholeheartedly. The theory in question also has astrophysical implications which are being rigorously examined at the present time.

Throughout the first decade of this century the so-called Brownian movement stimulated the keenest interest. In 1905 Einstein founded a kinetic theory to account for this movement by means of which he derived the chief properties of suspensions, i.e. liquids with solid particles suspended in them. This theory, based on classical mechanics, helps to explain the behaviour of what are known as colloidal solutions, a behaviour which has been studied by Svedberg, Perrin, Zsigmondy and countless other scientists within the context of what has grown into a large branch of science, colloid chemistry.

A third group of studies, for which in particular Einstein has received the Nobel Prize, falls within the domain of the quantum theory founded by Planck in 1900. This theory asserts that radiant energy consists of individual particles, termed "quanta", approximately in the same way as matter is made up of particles, i.e. atoms. This remarkable theory, for which Planck received the Nobel Prize for Physics in 1918, suffered from a variety of drawbacks and about the middle of the first decade of this century, it reached a kind of impasse. Then Einstein came forward with his work on specific heat and the photoelectric effect. This latter had been discovered by the famous

physicist Hertz in 1887. He found that an electrical spark passing between two spheres does so more readily if its path is illuminated with the light from another electrical discharge. A more exhaustive study of this interesting phenomenon was carried out by Hallwachs who showed that under certain conditions a negatively charged body, e.g. a metal plate, illuminated with light of a particular colour - ultraviolet has the strongest effect - loses its negative charge and ultimately assumes a positive charge. In 1899 Lenard demonstrated the cause to be the emission of electrons at a certain velocity from the negatively charged body. The most extraordinary aspect of this effect was that the electron emission velocity is independent of the intensity of the illuminating light, which is proportional only to the number of electrons, whereas the velocity increases with the frequency of the light. Lenard stressed that this phenomenon was not in good agreement with the then prevailing concepts.

An associated phenomenon is photo-luminescence, i.e., phosphorescence and fluorescence. When light impinges on a substance the latter will occasionally become luminous as a result of phosphorescence or fluorescence. Since the energy of the light quantum increases with the frequency, it will be obvious that a light quantum with a certain frequency can only

give rise to the formation of a light quantum of lower or, at most, equal frequency. Otherwise energy would be created. The phosphorescent or fluorescent light hence has a lower frequency than the light inducing the photo-luminescence. This is Stokes' rule which was explained in this way by Einstein by means of the quantum theory.

Similarly, when a quantum of light falls on a metal plate it can at most yield the whole of its energy to an electron there. A part of this energy is consumed in carrying the electron out into the air, the remainder stays with the electron as kinetic energy. This applies to an electron in the surface layer of the metal. From this can be calculated the positive potential to which the metal can be charged by irradiation. Only if the quantum contains sufficient energy for the electron to perform the work of detaching itself from the metal does the electron move out into the air. Consequently, only light having a frequency greater than a certain limit is capable of inducing a photo-electric effect, however high the intensity of the irradiating light. If this limit is exceeded the effect is proportional to the light intensity at constant frequency. Similar behaviour occurs in the ionisation of gas molecules and the so-called ionisation potential may be calculated, provided that the frequency of the light capable of ionising the gas is known. Einstein's law of the photo-electrical effect has been extremely rigorously tested by the American Millikan and his pupils and passed the test brilliantly. Owing to these studies by Einstein the quantum theory has been

perfected to a high degree and an extensive literature grew up in this field whereby the extraordinary value of this theory was proved. Einstein's law has become the basis of quantitative photo-chemistry in the same way as Faraday's law is the basis of electro-chemistry.**

* The Nobel Prize in Physics 1921 was announced on November 9, 1922.

** Being too remote from Sweden, Professor Einstein could not attend the ceremony.

From *Nobel Lectures, Physics 1901-1921*, Elsevier Publishing Company, Amsterdam, 1967

(46) Cyanide and carbon monoxide have high affinity for metal ions, tightly binding to form complexes (coordination compounds). For this reason, they are toxic. The main reason why ingestion/inhalation of these kills is because:

- (a) they irreversibly bind to the iron in haemoglobin, preventing oxygen transport hence inhibiting respiration
- (b) they bind to sodium and potassium ions, inhibiting cell function

- (c) they bind to metal cofactors in the active sites of critical enzymes and arrest metabolism
- (d) they bind all the calcium in the blood stream and prevent normal cellular functions

Answer:

Of options (a) and (c) (the other two options are completely wrong!), **(a) is more correct.** **Cyanide** is an irreversible enzyme inhibitor. Cyanide ions bind to the iron atom of the enzyme cytochrome c oxidase (also known as aa₃) in the fourth complex in the mitochondrial membrane in the mitochondria of cells. This denatures the enzyme, and the final transport of electrons from cytochrome c oxidase to oxygen cannot be completed. As a result, the electron transport chain is disrupted, meaning that the cell can no longer aerobically produce ATP for energy. Tissues that mainly depend on aerobic respiration, such as the central nervous system and the heart, are particularly affected. Plants contain a cyanide-insensitive pathway (photosynthesis instead of the redox reaction) for respiration in their mitochondria, and as a result are insensitive to concentrations of cyanide that are lethal to animals.

Carbon monoxide binds to hemoglobin (reducing oxygen transportation), myoglobin (decreasing its oxygen storage capacity), and mitochondrial cytochrome oxidase (inhibiting cellular respiration). Carbon monoxide has a significant

affinity to the iron (or copper) sites in hemoglobin, the principal oxygen-carrying compound in blood. The affinity between carbon monoxide and hemoglobin is 240 times stronger than the affinity between hemoglobin and oxygen. Carbon monoxide also has a high affinity for myoglobin. CO bound to myoglobin may impair cardiac output and result in cerebral ischemia. A second mechanism involves co-effects on the mitochondrial respiratory enzyme chain that is responsible for effective tissue utilization of oxygen. CO does not bind to cytochrome oxidase with the same affinity as oxygen so it likely requires significant intracellular hypoxia before binding. This binding interferes with aerobic metabolism and efficient adenosine triphosphate (ATP) synthesis. Cells respond by switching to anaerobic metabolism, causing anoxia, lactic acidosis, and eventual cell death.

- (47) Thus far, there have been seven parent and child Nobel Laureates in the fields of Chemistry, Physics, and Medicine and Physiology. Some of these (mothers sometimes retain their maiden names, which children do not share!) parent-child laureates are
- (a) Dorothy Hodgkin and Aaron Klug;
Marie Curie and Irene Joliot-Curie;

- Barbara McClintock and Sidney Brenner
- (b) Marie Curie and Irene Joliot-Curie;
William and Lawrence Bragg; Arthur and Roger Kornberg
- (c) William and Lawrence Bragg; James Watson and Francis Crick; Linus Pauling and Wolfgang Pauli
- (d) Nadine Gordimer and John M. Coetzee;
Kenichi Fukui and Ryoji Noyori; Albert Luthuli and Desmond Tutu

Answer:

Option (b) is correct.

The following comes from the Nobel Foundation website (www.nobelprize.org)

Family Nobel Laureates

(1) Mother & Daughter

Marie Curie (Physics, 1903; Chemistry, 1911)
Irène Joliot-Curie (Chemistry, 1935)

(2) Father & Son

- (a) William Bragg (Physics, 1915)
Lawrence Bragg (Physics, 1915)
- (b) Niels Bohr (Physics, 1922)
Aage N. Bohr (Physics, 1975)

- (c) Hans von Euler-Chelpin (Chemistry, 1929)
Ulf von Euler (Medicine or Physiology; 1970)
 - (d) Arthur Kornberg (Medicine or Physiology; 1959)
Roger D. Kornberg (Chemistry, 2006)
 - (e) Manne Siegbahn (Physics, 1924)
Kai M. Siegbahn (Physics, 1981)
 - (f) J. J. Thomson (Physics, 1906)
George Paget Thomson (Physics, 1937)
- (48) Depending on the reaction involved, titration experiments can be categorised into:
- (a) neutralization, complexometric and redox titrations
 - b) neutralization, polymerization and ion exchange titrations
 - (c) redox titrations, particle size exclusion and precipitation titrations
 - (d) homogeneous, heterogeneous and phase-transfer titrations

Answer:

Option (a) is correct. Different types of titration reaction include:

Acid-base titration is based on the neutralization reaction between the analyte

and an acidic or basic titrant. These most commonly use a pH indicator, a pH meter, or a conductance meter to determine the endpoint.

A Redox titration is based on an oxidation-reduction reaction between the analyte and titrant. These most commonly use a potentiometer or a redox indicator to determine the endpoint. Frequently either the reactants or the titrant have a colour intense enough that an additional indicator is not needed.

A Complexometric titration is based on the formation of a complex between the analyte and the titrant. The chelating agent EDTA is very commonly used to titrate metal ions in solution. These titrations generally require specialized indicators that form weaker complexes with the analyte. A common example is Eriochrome Black T for the titration of calcium and magnesium ions.

(49) The SI units for temperature, luminous intensity and power are:

- (a) degrees celsius, watt, joule
- (b) kelvin, candela, watt
- (c) degrees celsius, tesla, joule
- (d) kelvin, ampere, watt.

Answer:

Option (b) is correct. *Système Internationale d'Unités* (French) is the international decimal system of weights and measures derived from and extending the metric system of units. Adopted by the 11th General Conference on Weights and

Measures in 1960, it is abbreviated SI in all languages.

Rapid advances in science and technology in the 19th and 20th centuries fostered the development of several overlapping systems of units of measurements as scientists improvised to meet the practical needs of their disciplines. The early international system devised to rectify this situation was called the metre-kilogram-second (MKS) system. The General Conference on Weights and Measures added three new units (among others) in 1948: a unit of force (the newton), defined as that force which gives to a mass of one kilogram an acceleration of one metre per second per second; a unit of energy (the joule), defined as the work done when the point of application of a newton is displaced one metre in the direction of the force; and a unit of power (the watt), which is the power that in one second gives rise to energy of one joule. All three **units** are named for eminent scientists.

The 1960 International System builds on the MKS system. Its seven basic units, from which other units are derived, are currently defined as follows:

for length, the metre, defined as the distance traveled by light in a vacuum in $1/299,792,458$ second;

for mass, the kilogram, which equals 1,000 grams as defined by the international prototype kilogram of platinum-iridium in

the keeping of the International Bureau of Weights and Measures in Sèvres, France;

for time, the second, the duration of 9,192,631,770 periods of radiation associated with a specified transition of the cesium-133 atom;

for electric current, the ampere, which is the current that, if maintained in two wires placed one metre apart in a vacuum, would produce a force of 2×10^{-7} newton per metre of length;

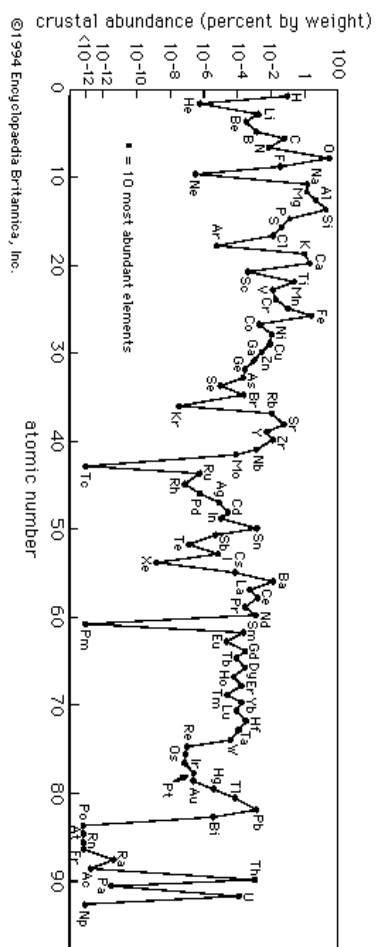
for luminous intensity, the candela, defined as the intensity in a given direction of a source emitting radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $1/683$ watt per steradian;

for amount of substance, the mole, defined as containing as many elementary entities of a substance as there are atoms in 0.012 kg of carbon-12; and

for thermodynamic temperature, the kelvin.

Note that *degree Celsius* (having the international thermometric scale on which the interval between the triple point of water and the boiling point of water is divided into 99.99 degrees with 0.01° representing the triple point and 100° the boiling point) and *degree centigrade* (having a thermometric scale on which the interval between the freezing point of water and the boiling point of water is divided into 100 degrees with 0° representing the freezing point and 100° the boiling point) are used interchangeably. Because there is a base unit for temperature already, they are only used commonly but not in the strict scientific sense.

- (50) The diagram below shows the chemical element abundances in the earth's crust for elements 1 to 93

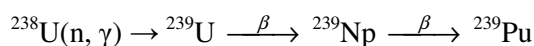


From the above diagram, approximately how many metric tons of earth will have to be processed in order to obtain 100 kilograms of pure plutonium?

- (a) 1.0×10^{13}
 (b) 1.99×10^8
 (c) 1.0×10^{17}
 (d) none of the above

Answer:

Plutonium (Chemical symbol Pu, and named after Pluto, once regarded as a planet) is element number 94, and does not appear in the diagram depicted. Thus, **the correct answer is (d)**. Plutonium, a metal, was the second trans-uranium element of the actinide series to be discovered. The isotope ^{238}Pu was produced in 1940 by Glenn Seaborg and co-workers by deuteron bombardment of uranium in the 60-inch cyclotron at Berkeley, California. Plutonium also exists in trace quantities in naturally occurring uranium ores. It is formed in the same manner as neptunium (Np); by irradiation of natural uranium with the neutrons which are present. By far of the greatest importance is the isotope ^{239}Pu , with a half-life of 24 100 years, which is produced in extensive quantities in nuclear fission from natural uranium:



The key use of plutonium is in nuclear weapons as well as in nuclear power generation. The complete detonation of a kilogram of plutonium produces an explosion equal to 20 000 tons of chemical explosive. As a power source, one kilogram is equivalent to 22 million kilowatt hours of heat energy. The metal has a silvery appearance and takes on a yellow tarnish when slightly oxidised. It is chemically reactive and is warm to touch because of the energy it gives off in alpha decay. In fact, larger pieces of plutonium will produce enough energy to boil water!