1. The density of water, $H_2O(l)$, is 1.0 g mL^{-1}. How many **atoms** of hydrogen are present in 2.5 L of pure water?

.

A) 1.5×10^{27}
B) 2.7×10^{26}
C) 8.1×10^{25}
D) 1.7×10^{26}
E) 2.3×10^{-22}

D.

The mass of 2.5 L of water is 2500 mL x 1.0 g mL^{-1} = 2500 g. Since the molar mass of water is 18.015 g mol^{-1}, there is 2500/18.015 mol = 138.8 mol of water. This corresponds to $6.022 \times 10^{23} \times 138.8 = 8.36 \times 10^{25}$ molecules of water. There are two hydrogen atoms per water molecule - i.e., $2 \times 8.36 \times 10^{25} = 1.7 \times 10^{25}$ atoms of hydrogen. Note that the final answer has two significant digits.

2. How many **moles of ions** – both cations and anions – are present in solution when 0.75 mol of potassium chloride (KCl) is dissolved in 0.25 L of distilled water?

.

A) 3.0
B) 2.0
C) 1.5
D) 0.8
E) 0.7

C.

The given volume is not needed. When potassium chloride dissolves in water it is present as separate $K^+(aq)$ and $Cl^-(aq)$ ions. There are two moles of ions per mole of dissolved KCl - i.e., 2 x 0.75 = 1.5 moles of ion in the given solution.

3. How many grams of NaOH are required for complete neutralization of 50.0 mL of 0.168 mol L^{-1} H_2SO_4? The products are sodium sulfate and water.
.

A) 0.00388
B) 0.00776
C) 0.206
D) 0.170
E) 0.672

E.
The balanced equation for this neutralization reaction is

$$2\ NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2\ H_2O(l)$$

i.e., two moles of NaOH are consumed for every one mole of H_2SO_4.
Moles of H_2SO_4 = concentration x volume = 0.168 mol L^{-1} x 0.0500 L = 0.00840 mol
Neutralization of 0.00840 mol H_2SO_4 requires 2 x 0.00840 mol = 0.0168 mol NaOH
Mass of NaOH = 40.00 g mol^{-1} x 0.0168 mol = 0.672 g.

4. The empirical formula of a compound is CH. At 200 °C, 0.868 g of this compound in the gas phase occupies a volume of 97.2 mL at a pressure of 4.5 bar. What is the molecular formula of the compound?
.

A) C_8H_8
B) C_5H_5
C) C_2H_2
D) C_7H_7
E) C_6H_6

E.
The amount of this compound,
$n = P\ V\ /(R\ T)$ = 4.5 bar x 0.0972 L / (0.08314 L bar K^{-1} mol^{-1} x 473.15 K) = 0.0111 mol
The molar mass of the compound is 0.868 g / 0.0111 mol = 78.2 g mol^{-1}
~= 6 x 13.02 g mol^{-1} (13.02 g mol^{-1} is the molar mass of CH)
The compound is C_6H_6.

5. Neutral atoms of ^{16}O, ^{17}O and ^{18}O **all** have:
   .

A) 8 neutrons and 8 protons
B) 16 protons and 16 electrons
C) 8 neutrons
D) 16 protons
E) 8 electrons and 8 protons

E.
The different oxygen isotopes all have atomic number 8 (i.e., they all have 8 protons), but different number of neutrons. Since the atoms are neutral, the number of electrons is the same – i.e., 8.

6. As in experiment # 1, a HCl(aq) solution with known concentration is titrated with a NaOH(aq) solution of unknown concentration. Which of the following errors would **NOT affect** the accurate determination of [NaOH]?
   .

A) Some pure water is added to the beaker containing 10.00 mL HCl(aq), before it is titrated.
B) When 10.00 mL HCl solution is being transferred to a beaker, some solution drips out of the pipette onto the lab bench.
C) Some NaOH solution is added after a faint pink color is observed.
D) There was water in the beaker used to collect the HCl stock - i.e., before pipetting into a second beaker for titration.
E) The miniscus in the buret dropped below the 50.00 mL mark.

A.
Once the 10.00 mL HCl(aq) stock solution is added to a beaker – to be titrated – the number of moles of HCl is fixed at a known amount. Adding some water to this beaker does not affect the number of moles of HCl, and consequently does not affect the final determined concentration of NaOH. Error B gives an unknown lower number of moles of HCl. Error C gives a volume of NaOH solution that is larger than that needed for neutralization. The resulting determined concentration of NaOH will be too small. Error D dilutes the HCl stock solution. Fewer moles of HCl are added than is used in the calculations. The resulting determined concentration of NaOH will be too large. Error E results in an imprecisely determined volume of added titrant.

7. The number of **grams of nickel** required to produce 24.0 g of nickel boride, Ni_2B, is .

A) 16.0
B) 22.0
C) 0.9
D) 2.00
E) 116

B.

The molar mass of Ni_2B is 128.20 g mol^{-1}.
Moles of Ni_2B = 24.0 g / 128.20 g mol^{-1} = 0.1872 mol.
Each mole of Ni_2B has two moles of Ni.
Moles of Ni = 0.3744 mol.
Mass of Ni = 58.69 g mol^{-1} x 0.3744 mol = 22.0 g

8. The metal filament used in incandescent light bulbs is tungsten (W). The work function (i.e., the binding energy of an electron to the surface of the metal) of tungsten is 431 kJ mol^{-1}. What is the **longest wavelength** of light (in nm) – the threshold wavelength – that will cause an electron to be ejected from this metal? .

A) 7.16×10^{-19}
B) 278
C) 461
D) 926
E) 3.60 10^9

B.

Per electron, the work function is 431 x 10^3 J mol^{-1} / 6.022 x 10^{23} mol^{-1} = 7.157 x 10^{-19} J.
The threshold frequency is 7.157 x 10^{-19} J / 6.626 x 10^{-34} J s = 1.080 x 10^{15} s^{-1}.
The threshold wavelength is 2.998 x 10^8 m s^{-1} / 1.080 x 10^{15} s^{-1} = 2.776 x10^{-7} m = 278 nm.

9. Which one of the following atoms is **diamagnetic** (slightly repelled by a magnet) **in its ground state**?
.
A) Cl
B) Fe
C) K
D) Si
E) Zn

E.

All subshells of Zn are filled. It has ground state electron configuration, [Ar] $4s^2$ $3d^{10}$.

10. Which of the following electron configurations are **excited states** of a group 14 atom?
(i) $1s^2 2s^2 2p^2$ (ii) $1s^2 2s^2 2p^3$ (iii) $1s^2 2s^1 2p^3$ (iv) $1s^2 2s^1 2p^5$
(v) $1s^2 2s^1 2p^2 3d^1$
.
A) i and ii
B) ii and iii
C) ii and iv
D) iii and v
E) i and v

D.

i is the ground state electron configuration for carbon – in group 14. ii has 7 electrons – group 15. iv has 8 electrons – group 16.

11. An arsenic atom (Z = 33) is in its ground state. Which one of the following sets of quantum numbers (n, ℓ, m_ℓ, m_s) could **not** possibly describe one of its electrons?
.
A) 2, 1, –1, 1/2
B) 3, 0, 0, –1/2
C) 3, 2, –2, 1/2
D) 4, 1, 0, 1/2
E) 4, 2, 2, –1/2

E. These quantum numbers are for a 4d electron. The ground state electron configuration of arsenic is $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $4s^2$ $3d^{10}$ $4p^3$. There are no 4d electrons in this configuration.

12. What frequency of light in Hz (1 Hz = 1 s^{-1}) is needed to promote an electron of a hydrogen atom from the energy level n = 2 to the energy level n = 3?

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A) 4.57×10^{14}
B) 2.75×10^{38}
C) 3.03×10^{-17}
D) -3.03×10^{17}
E) 2.00×10^{-52}

A.
$\Delta E = R_E (1/2^2 - 1/3^2) = 2.18 \times 10^{-18}$ J x (0.25 – 0.11) = 3.03×10^{-19} J = $h\,v$
So, $v = 3.03 \times 10^{-19}$ J / 6.626×10^{-34} J s = 4.57×10^{14}.

13. A detector receives a signal consisting of green light, with a wavelength of 540 nm. The total energy of the signal is 2.5×10^{-14} J. How many photons reach the detector?

.

A) 2.1×10^{-5}
B) 1.5×10^{4}
C) 6.8×10^{4}
D) 1.5×10^{7}
E) 6.8×10^{7}

C.
Each photon has energy, $h\,v = h\,c\,/\,\lambda = 6.626 \times 10^{-34}$ J s x 2.998×10^{8} m s^{-1} / 540×10^{-9} m
= 3.68×10^{-19} J.
The total energy of the signal results from 2.5×10^{-14} J / 3.68×10^{-19} J = 6.8×10^{4}

14. Which of the following statements is(are) **true**?

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(i) The ground-state electron configuration of magnesium has no unpaired electron.
(ii) $1s^2 2s^2 2p^3 3s^1$ represents the ground-state electron configuration of an oxygen atom.
(iii) An aluminum atom in its ground state is paramagnetic.
(iv) In the ground-state of a fluorine atom, no electron has a magnetic quantum number, m_ℓ, equal to 2.

.

A) i, ii, iii
B) ii, iv
C) i, ii
D) i only
E) i, iii, iv

E.
The electron configuration of the ground state of oxygen is $1s^2 2s^2 2p^4$. The given configuration is for an excited state.

15. Which one of the following is the **correct** size sequence?
    .
    A) $Ca^{2+} < K^{+} < K < Cl^{2-}$
    B) $K < Cl^{2-} < K^{+} < Ca^{2+}$
    C) $Cl^{2-} < K < Ca^{2+} < K^{+}$
    D) $K < K^{+} < Cl^{2-} < Ca^{2+}$
    E) $Ca^{2+} < Cl^{2-} < K^{+} < K$

A.
$Ca^{2+} < K^{+}$ both have 18 electrons (calcium has a larger nuclear charge).
$K^{+} < K$
$K < Cl^{2-}$ both have 19 electrons (potassium has a larger nuclear charge).

16. Which one of the following atoms has the **largest** first ionization energy? (Hint: consider the ground state electron configurations for these atoms.)
    .
    A) Si
    B) S
    C) P
    D) Al
    E) K

C.
The general trend is first ionization energy decreases from left to right across a period, and going down a group. Sulfur is the topmost/rightmost of these elements. However, phosphorus has a half-filled p subshell, and has a higher first ionization energy than sulfur.

17. Which one of the following **decreases** in magnitude across a row of the periodic table, from left to right?
    .
    A) Effective nuclear charge
    B) Atomic radius
    C) Ionization energy
    D) Electron affinity
    E) Electronegativity

B.

18. Select the correct sequence of elements.in order of **increasing atomic radius**.
    .
    A) O < Ne < P < Ga
    B) Ne < O < P < Ga
    C) Ga < P < O < Ne
    D) Ga < P < Ne < O
    E) O < Ne < Ga < P

B.
The general trend is atomic radius increases from right to left across a period, and going down a group. Thus, Ne < O. Also, **O** < S < **P** < As < Ge < **Ga**.

19. An element is a molecular solid at room temperature. It burns to form an acidic solid oxide – i.e., it forms an acidic solution when dissolved in water. The element's first ionization energy is higher than either of its neighbouring elements (to the left and right) in the periodic table. **Which element is this**?
    .
    A) Al
    B) Si
    C) P
    D) S
    E) Cl

C.
Group 2 and 15 atoms have higher first ionization energy than their periodic table neighbors.
P is a non-metal in group 15. It exists as $P_4(s)$ and forms $P_4O_6(s)$ or $P_4O_{10}(s)$.

20. Put the following atoms in order of **increasing magnitude of electron affinity**:
    .

A) F < O < C < B < Be
B) B < Be < C < F < O
C) Be < B < C < O < F
D) Be < C < B < F < O
E) B < Be < C < O < F

C.
The general trend is magnitude of electron affinity increases from left to right across a period. However, Be – with a filled 2s subshell – has a positive (unfavorable) electron affinity. It comes first in this series. Otherwise, the series follows the general trend.