The Physics Experience of Chemistry Students Part I

Introduction

We are accustomed to dealing with the mathematical deficiencies of our students, but have paid little attention to similar problems with physics. The majority of students have not studied physics beyond GCSE level and it is appropriate to consider the consequences of this. Most of these are obvious, but like all such conclusions, it is useful to gather them together to focus attention.

- The majority of students take GCSE double science. The implication is that they have studied biology, chemistry and physics (three subjects) in space allocated to two subjects.
- Students who do not continue with physics beyond this stage will have had a gap of at least two years before entering university. There will have been no reinforcement of this knowledge and they are likely to have forgotten most of what they learned before. Students who I have interviewed could recall few, if any, of the 'essential equations' listed at the end of this article.
- The GCSE syllabus itself is minimalist – see the summary attached to this document.

The requirements

A typical chemistry course will need background to the following items during the first two years.

- Electromagnetic spectrum: gamma rays to radio waves (wavelength and frequency).
- Quantization: black-body radiation and UV catastrophe; photoelectric effect; existence of atomic spectra.
- Waves and particles: idea of Compton effect; diffraction of light; de Broglie; existence of quantum mechanics.
- Atomic structure: spectrum of H atom; ideas behind H atom description in quantum mechanics.
- Kinetic and potential energy. Pressure and force.
- Laws of motion. Inertia and moments.

It is safe to assume that this background does not exist and it would be wise to assume that even the simplest equations (e.g. $c = v\lambda$, $KE = ½mv^2$) have been forgotten.

The syllabus

The following pages outline, in some detail, the typical GCSE physics (double subject) syllabus studied in the UK. The boxes contain the additional material to be found in the A-level syllabus. Note here that I have included only those items (at A-level) relevant to chemistry. The last page contains the 'essential equations' that all examining boards must expect students to recall and use (any others will be given to the student).

As an example notice that the concept of spectroscopy arising from differences in energy levels does not appear until A-level.

The Higher Education Academy UK Physical Sciences Centre

Energy and Electricity

Units

Candidates will be assessed on their ability to use the following units:

volt (V), ampere (A), ohm (W), watt (W), kilowatt-hour (kWh)

Circuits

Candidates will be assessed on their ability to:

recall that cells and batteries supply direct current and **understand** that direct current (d.c.) passes in one direction only

explain how changing the resistance in a circuit changes the current and how this can be achieved using a variable resistor

recall and use the equation

voltage (V) = current (A) × resistance (Ω)

$$V = I \times R$$

Mains Electricity

Candidates will be assessed on their ability to:

recall that the mains supply is alternating current and **understand** that alternating current (a.c.) changes direction

recall that the mains supply can provide dangerous currents which can cause serious injury, or death, to users

understand that when an electric current passes through a resistor there is an energy transfer and the resistor is heated

describe how the heating effect of an electric current is used in a variety of appliances, such as

electric bar heaters, immersion heaters, kettles, cookers and irons

understand that energy from the mains supply is measured in kilowatt-hours

use the equation given below for calculating the cost of electricity

cost = power (kW) × time (h) × cost of 1 kWh

(This equation will be provided if required)

Electric current as rate of flow of charge.

$$I = \Delta Q/\Delta t$$

Law of conservation of charge applied to currents at a junction.

Use of ammeters.

An understanding of the equation

$$I = nAQv$$

The distinction between metals, semiconductors and insulators in terms of this equation. Typical carrier drift speeds in metals should be known.

p.d. as work done/charge

i.e. $V = W/Q$

or as power/current

i.e. $V = P/I$

Electrical working.

$$\Delta W = IV\Delta t$$

Use of voltmeters.

Measurements and typical graphs for wire filament lamp, ohmic resistor and semiconductor diode.

Ohm's law.

Experimental measurement of resistivity.

$$P = IV = I^2R = V^2/R$$

Formulae for resistors in series and in parallel:

Use of ohmmeters.

Waves, atoms and space

Units

Candidates will be assessed on their ability to use the following units:

hertz (Hz), metre (m), newton per kilogram (N/kg)

Waves

Candidates will be assessed on their ability to:

describe longitudinal and transverse waves in terms of frequency, wavelength and amplitude

recall that the electromagnetic spectrum includes radio waves, microwaves, infra-red (IR), visible, ultraviolet (UV), X-rays and gamma rays

recall the order of the electromagnetic spectrum in decreasing wavelength and increasing frequency including the colours of the visible spectrum

recall that the energy associated with an electromagnetic wave, and thus its potential danger, increases with increasing frequency

recall that all electromagnetic waves are transverse and travel at the same speed in a vacuum

understand some uses of electromagnetic radiation including

> radio waves: broadcasting and communications including satellite transmissions, microwaves: cooking and communications including satellite transmissions, infra-red: grills, night vision, remote controls, security systems and treatment of muscular problems, visible light: vision and photography, ultraviolet: sun beds, security marking, fluorescent lamps and detecting forged bank notes, X-rays: observing the internal structure of objects and materials including the human body, gamma rays: sterilising food and medical equipment, and treatment of cancers

understand the detrimental effects of excessive exposure of the human body to

> microwaves: internal heating of body tissue, infra-red: skin burns, ultraviolet: damage to surface cells (including skin cancer) and eyes, X-rays: damage to cells

describe the change of direction of light as it enters glass from air and as it leaves glass into air (e.g. glass block, glass prism)

understand the refraction of light in terms of the change of speed when light crosses a boundary

recall that sound is transmitted as a longitudinal wave

understand that sound with frequencies greater than 20,000 Hz is known as ultrasound and

recall that human ears detect a limited range of frequencies

describe the use of ultrasound in medical imaging and echo sounding.

Sources of background radiation. Ionising properties of radiations linked to penetration and range.

The balancing of nuclear equations.

Isotopes.

Activity and the becquerel.

The constant ratio property of exponential curves.

The use of e^x and $\log_e x$ are not required.

$$\lambda t_{½} = 0.69$$

The experimental determination or modelling of half-life.

Size of atoms. Relative size of nuclei. Scattering as a means of probing matter.

Alpha particle scattering experiment in broad outline.

The use of electrons of high energy to reveal the structure of protons and neutrons.

Atoms

Candidates will be assessed on their ability to:

understand the terms atomic (proton) number and mass (nucleon) number and explain the existence of isotopes

use symbols such as $^{14}_{6}C$ to describe particular nuclei

understand that radioactivity arises from the breakdown of an unstable nucleus of an atom and is a random process

recall the three main types of radiation from radioactive sources and their comparative mass, charge and ionisation ability

describe the properties of alpha and beta particles and gamma radiation, including their penetrating powers and their uses in smoke alarms, for controlling the thickness of sheet material and sterilising medical instruments

recall the existence of background radiation from the Earth and from space including the regional variations in the United Kingdom, e.g. because of radon gas released from rocks.

Movement and change

Units

Candidates will be assessed on their ability to use the following units

second (s), metre (m), metre per second (m/s), metre per second^2 (m/s^2), kilogram (kg), joule (J), newton (N), newton per kilogram (N/kg), watt (W), becquerel (Bq)

Forces and motion

Candidates will be assessed on their ability to:

interpret distance-time graphs including determination of speed from the gradient of a graph

recall that velocity is speed in a stated direction

recall and use the equation

acceleration (m/s^2) =

change in velocity (m/s) / time taken (s)

$a = (v-u) / t$

interpret speed/time graphs

determine the acceleration from the gradient of the graph

determine the distance travelled from the area between the curve and the time axis

understand that the stopping distance of a vehicle is made up of

thinking distance, braking distance

understand the factors affecting the stopping distance of a vehicle, including

the mass of the vehicle, the speed of the vehicle, the driver's reaction time

recall a brief history of our understanding of forces and how they affect motion in a straight line including

the Greek view - a simple force needed to sustain motion, Galileo and Newton - balanced forces allow an object to continue in uniform motion in a straight line or to remain at rest, Newton - gravitational attraction acts between all masses

understand that when object A pulls or pushes object B then object B pulls or pushes object A with a force that is equal in size and opposite in direction

understand that falling objects are acted on by a downward force (weight) and an upward force (air resistance) and that at the start of the fall the forces are unbalanced and the object accelerates

understand that, when an object falls through the atmosphere, air resistance increases with increasing speed until it is equal in size to the weight of the falling object, when terminal speed (velocity) is reached

$v = u + at$

$x = ut + ½at^2$

$v^2 = u^2 + 2ax$

Identify and use the physical quantities derived from the gradient and area of velocity – time graphs and the gradient of displacement – time graphs.

Familiarity with gravitational, electric, magnetic and nuclear forces; normal and frictional contact forces; viscous and drag forces; tension.

Weight = mg

Centre of gravity.

Bodies in equilibrium. Vector forces on body sum to zero.

Moment of F about O =

F × (perpendicular distance from F to O).

For a rigid body in equilibrium, sum of clockwise moments about any point = sum of anticlockwise moments about that point.

Measurement of the density of solids, liquids and gases.

Application of r = m/V

Momentum defined as p = m v

Applications of SF = ma

Work done = average applied force multiplied by the distance moved in the direction of the force.

$\Delta W = F \Delta x$

Calculation of work done when force is not along the line of motion.

Energy transfer when work is done.

k.e. = $½mv^2$

Changes in gravitational potential energy close to the Earth's surface.

$\Delta E = mg\Delta h$

Qualitative study and quantitative application of conservation of energy, including use of work done, gravitational potential energy and kinetic energy.

Rate of energy transfer (or of work done).

$P = \Delta W/\Delta t$

$P = Fv$

understand that in the absence of air, all falling bodies accelerate at the same rate

describe the forces acting on a car moving in a straight line on a horizontal surface
the driving force, the resistive force

in the above example, **understand** how the balance of forces differs when the car is
accelerating, braking, moving at a constant speed

understand that when an unbalanced force acts on an object, the acceleration depends on
the size of the unbalanced force, the mass of the object

recall and use the equation

$$\text{force (N)} = \text{mass (kg)} \times \text{acceleration (m/s}^2\text{)}$$

$$F = m \times a$$

Forces and energy

Candidates will be assessed on their ability to:

recall and use the equation

$$\text{work done (J)} = \text{force (N)} \times \text{distance moved in the direction of the force (m)}$$

$$W = F \times d$$

understand that gravitational potential energy is stored positional energy, e.g. a swimmer on a diving board, a person lifting weights

recall and use the equation

$$\text{gravitational potential energy (J)} = \text{mass (kg)} \times \text{gravitational field strength (N/kg)} \times \text{vertical height (m)}$$

$$GPE = m \times g \times h$$

recognise the equivalence of work done and energy transfer and **recall** that energy transferred (J) = work done (J)

understand that power is the rate of doing work and is measured in watts (joules per second)

recall that kinetic energy is movement energy

recall and use the equation

$$\text{kinetic energy (J)} = 1/2 \times \text{mass (kg)} \times \text{velocity}^2 \text{ (m/s)}^2$$

$$KE = 1/2 \times m \times v^2$$

Using half life

Candidates will be assessed on their ability to:

understand that the activity of a radioactive isotope decreases over a period of time and is measured in becquerels

recall that the half-life of a radioactive isotope is the time taken for half the undecayed nuclei to decay, and the consequent problems arising in the disposal of radioactive waste

use the concept of half-life to carry out simple calculations on the decay of a radioactive isotope

describe the uses of radioactivity in the radioactive dating of archaeological specimens and rocks

Energy, force and communication

Units

Candidates will be assessed on their ability to use the following units:

coulomb (C), ampere (A), volt (V), power (W), second (s), metre (m), hertz (Hz), metre per second (m/s), newton (N), newton metre (Nm)

Charge and energy

Candidates will be assessed on their ability to:

describe common materials which are electrical conductors or insulators including metals and plastics

describe how an insulator can be charged by friction, resulting in the transfer of electrons

recall that like charges repel and unlike charges attract

describe common electrostatic phenomena in terms of movement of electrons, for example

shocks from car doors, charges on synthetic fabrics, lightning

describe some of the uses and dangers of electrostatic charges in everyday situations, e.g. fuelling aircraft and tankers, photocopiers and inkjet printers

explain how earthing removes the excess charge on a body, with reference to the movement of electrons

understand that current is rate of flow of charge

$F = kQ_1Q_2 / r^2$ where, for free space (or air)
$k = 1 / 4\pi e_0 = 9.0 \times 109$ N m^2 C^{-2}
$C = Q/V$

Waves and communication

Candidates will be assessed on their ability to:

recall that waves transfer energy and information without transferring matter

recall and use the equation for all waves:

wave speed (m/s) = frequency (Hz) × wavelength (m)

$$v = f \times \lambda$$

understand the condition for total internal reflection to take place and how this is used in optical fibres and in reflecting prisms

recall that waves spread out when they pass through a narrow gap or past an edge and that this is called diffraction

understand that sound and light show diffraction effects

describe and interpret some examples of diffraction, e.g.

of sound by large building/doorways, of water waves by harbours, of light by a single narrow slit

$\omega = \Delta q / \Delta t$ $v = \omega r$ $T = 2\pi/\omega$ $f = \omega/2\pi$

For a body moving at a constant speed in a circular path, acceleration $a = v^2/r$.

Resultant force F towards the centre of the circle equals mv^2/r.

An understanding that s.h.m. results when acceleration is proportional to displacement and in the opposite direction.

The equation $a = -(2\pi f)^2x$; $T = 1/f$.

$$x = x_0 \cos 2\ ft$$

The Planck constant.

$$E = hf$$

Maximum energy of photoelectrons

$$= hf - \varphi$$

Possible energy states of an atom as fixed and discrete.

$$hf = E_1 - E_2$$

The emission and absorption line spectrum of atomic hydrogen related to electron energy levels.

Electron diffraction. The de Broglie wavelength.

$$\lambda = h/p$$

Wave properties of electrons in atoms.

Demonstration of spectra using a diffraction grating. Star spectra emission and absorption lines and their relation to chemical composition.

Forces and shape

Candidates following the Welsh National Curriculum should be taught the principle of moments and its application to situations involving one pivot in order to meet statutory requirements.

Candidates will be assessed on their ability to:

understand that the upward forces on a light beam supported at its ends vary with the position of a heavy object placed on the beam

describe how extension varies with applied force for a range of materials including springs and rubber bands

recall that particles in a gas have random motion and that they exert a force on the walls of the container

understand the relationship between the pressure and volume of a fixed mass of gas at constant temperature and use the quantitative relationship

$$P_1V_1 = P_2V_2$$

Measurement of specific heat capacities of solids and liquids: a direct method using an electric heater will be expected.

Emphasis on calculation of energy transferred. Sources of serious experimental error should be identified and understood.

Specific heat and latent heat. Direct experimental methods only. A method using an electric heater will be expected.

Solids transmit force, fluids transmit pressure.

Application of $p = F/A$

Experiment demonstrating that for a fixed mass of gas at constant V

$$p/T = \text{constant}$$

Concept of absolute zero of temperature.

$$T/\text{K} = \Theta/^\circ\text{C} + 273$$

Experiment demonstrating that for a fixed mass of gas at constant T

$$pV = \text{constant}$$

For ideal gases

$$pV = nRT$$

In calculations the amount of gas will be given in moles.

The assumptions on which the model is founded.

$$p = 1/3\ \rho \langle c^2 \rangle$$

Average kinetic energy of molecules proportional to kelvin temperature.

Use of the model to explain the change of pressure with temperature.

For real gases the random distribution of potential and kinetic energy amongst molecules. Appreciation that hot and cold objects have different concentrations of internal energy.

Random interchange of energy between bodies in thermal contact, resulting in energy flowing from hot to cold.

The increase in internal energy equal to the sum of the energy given by heating and working.

Work done by engine when energy flows from a hot source to a cold sink.

Efficiency of energy transfer as useful output divided by input.

Maximum thermal efficiency = $(T_1 - T_2)/T_1$

Work needed to pump energy from cold to hot.

The following two modules are taken ONLY by students sitting the single subject version

Communications

Units

Candidates will be assessed on their ability to use the following units

metre (m), second (s), metre/second (m/s), metre/second^2 (m/s^2), newton (N), hertz (Hz)

Transmitting and receiving radio waves

Candidates will be assessed on their ability to:

understand that the amount of diffraction depends upon wavelength and physical dimensions involved

recall and use the relationships between wave speed (v), frequency (f) and wavelength (l)

$$v = f \times \lambda \qquad f = v/\lambda \qquad \lambda = v/f$$

recall that amplitude modulation (AM) and frequency modulation (FM) are used in radio communications and **understand** the difference between them

Particles

Units

Candidates will be assessed on their ability to use the following units

kelvin (K), coulomb (C), ampere (A), volt (V), joule (J), pascal (Pa), speed (m/s)

Ideal gas molecules

Candidates will be assessed on their ability to:

understand that there is an absolute zero of temperature which is -273°C

describe the kelvin scale of temperature and be able to convert between the kelvin and Celsius scales

understand that an increase in temperature results in an increase in speed of gas particles and that the kelvin temperature of the gas is proportional to their average kinetic energy

explain the pressure exerted by a gas in terms of the motion of its particles

describe the qualitative relationship between pressure and kelvin temperature for a gas in a sealed container

use the quantitative relationship between the pressure and the kelvin temperature

$$P_1 / T_1 = P_2 / T_2$$

(This equation will be provided if required**)**

Atoms and nuclei

Candidates will be assessed on their ability to:

describe the results of Geiger and Marsden's experiments with gold foil and α particles

describe Rutherford's nuclear model of the atom and how it accounts for the results of Geiger and Marsden's experiment and **understand** the factors (charge and speed) which affect the deflection of α particles by a nucleus

recall the qualitative features of the curve obtained when the number of neutrons *(*N) is plotted against the number of protons (Z) for stable isotopes

understand that if an isotope does not lie on this curve it will be unstable and radioactive

recall that an isotope that lies above the curve has too many neutrons to be stable and will undergo β^- decay (emit an electron)

understand that in the process of β^- decay a neutron becomes a proton plus an electron

understand that in the process of β^+ decay a proton becomes a neutron plus a positron

describe the effects on the proton (atomic) and mass numbers of a nucleus of β^- and β^+ decay

recall that nuclei with greater than 82 protons usually undergo α decay

recall that as a result of β^- or β^+ decay nuclei often undergo rearrangement with a loss of energy as γ radiation

understand that a nucleus of U-235 can be split (fission) by collision with a neutron and that this process releases energy in the form of kinetic energy of the fission products

recall that the fission of U-235 produces two daughter nuclei and a small number of neutrons

understand that a chain reaction can be set up if the neutrons produced by one fission strike other U-235 nuclei

describe in outline how the fission process can be used as an energy source to generate electricity

understand that the products of nuclear fission are radioactive and the implications this has for their safe storage over prolonged periods

Electrons and other particles

Candidates will be assessed on their ability to:

recall that the electron is a fundamental, negatively charged particle

recall that the proton and neutron are not fundamental particles but each contains three particles called quarks

recall that the positron is a fundamental, positively charged particle with the same mass as the electron

recall that there are two types of quark in protons and neutrons and that β decay occurs when one quark changes to the other type, which in turn causes the neutron to become a proton (β^- decay) or the proton to become a neutron (β^+ decay)

understand that electrons are 'boiled off' hot metal filaments and this is called thermionic emission

understand the principles of a simple electron gun with a heated cathode and accelerating anode

use the quantitative relationship between kinetic energy gained, electronic charge and accelerating voltage

$$\text{kinetic energy} = \text{electronic charge} \times \text{accelerating voltage}$$

$$KE = e \times V$$

(This equation will be provided if required)

recall that a beam of electrons is equivalent to an electric current and perform simple calculations involving the rate of flow of electrons and the current, given the electronic charge

Briefing papers are designed to provide a condensed discussion on issues and topics related to teaching and learning in the physical sciences. Each guide focuses on a particular aspect of higher education and is written by an academic experienced in that field.

Essential Equations

(i) the relationship between speed, distance and time:

speed = distance / time taken

(ii) the relationship between force, mass and acceleration:

force = mass × acceleration

acceleration = change in velocity / time taken

(iii) the relationship between density, mass and volume:

density = mass / volume

(iv) the relationship between force, distance and work:

work done = force × distance moved in direction of force

(v) the energy relationships:

energy transferred = work done

kinetic energy = ½ × mass × speed^2

change in potential energy = mass × gravitational field strength × change in height

(vi) the relationship between mass, weight and gravitational field strength:

weight = mass × gravitational field strength

(vii) the relationship between an applied force, the area over which it acts and the resulting pressure:

pressure =force / area

(viii) the relationship between the moment of a force and its distance from the pivot:

moment = force × perpendicular distance from pivot

(ix) the relationships between charge, current, voltage, resistance and electrical power:

charge = current × time

voltage = current × resistance

electrical power = voltage × current

(x) the relationship between speed, frequency and wavelength:

wave speed = frequency × wavelength

(xi) the relationship between the voltage across the coils in a transformer and the number of turns in them.

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