Appendices to accompany SCORE's response to the Department for Education consultation on GCSE criteria

Response from the Institute of Physics, the the Society of Biology, the Royal Society of Chemistry and the Association for Science Education

20 August 2013

The appendices that follow have been compiled by individual SCORE organisations, with contributions from their members and committees. There may therefore be contradictions between them.

Appendix 1: Feedback from the Institute of Physics (page 2-25)

Appendix 2: Feedback from the Society of Biology (26-39)

Appendix 3: Feedback from the Royal Society of Chemistry (Page 40-58)

Appendix 4: Feedback from the Association for Science Education (Page 59)

Appendix 1

Appendix 1a. Feedback from the Institute of Physics on the criteria for GCSE physics and the physics content for double award science.

These comments draw on comments from the Institute's Education Forum.

- The statements should define content areas that should be studied and should not have command words. We have therefore suggested a different stem (which is similar to those used in other subjects).
- We welcome the inclusion of example uses of mathematics within each topic. We have suggested that these sections be structured differently with a heading of the area of mathematics (taken from the appendix of mathematical content) followed by exemplars from that topic. It should be made clear to Awarding Organisations that these examples should not be seen as limiting.
- We would like to see similar sections within each topic on example ways of developing practical skills – both procedural knowledge and technical, manipulative skills. These need to be developed.
- Similarly, we would like to see a section that illustrates how ideas in physics can be developed within each topic. This will help give students a feeling for the bigger picture and allow the subject to be taught in a cultured way, developing ways of thinking as well as knowledge of content.
- There is still a need to include more modern physics.
- We would like to see a clearer definition of the purpose of the double award in science. Only then will it be possible to determine what content should be included. However, if possible, it would be preferable to remove whole topics than to remove selected statements within the topics.

- The following sections represent a proposal for the style and possible content for the GCSE criteria. They also represent a more realistic amount of content that can be covered fully and properly in a GCSE course.

  They are based on the original criteria with some changes to content and style. We submit them as a proposal for further discussion and development.

Appendix 1

Forces

Specifications and assessment schemes should ensure that students study:

Forces and interactions

- examples of ways in which objects interact: gravity, electrostatics, magnetism and by contact (including normal contact force and friction);
- weight as a quantity; the force due to gravity experienced by a mass in a gravitational field; gravitational field strength;
- interactions between pairs of objects producing a force on each object;
- force as a vector quantity;

Forces on objects

- identifying and analysing forces on an isolated solid object or system;
- representing forces on free body diagrams;
- net force on an object and the special case of balanced forces when the net force is zero;
- stretching, compressing and bending objects by applying more than one force;
- elastic and inelastic distortions;
- relationship between force and extension for a spring and other simple systems; spring constant and Hooke's law;
- storage and dissipation of energy in elastic and inelastic deformations.

Pressure and pressure differences in fluids

- pressure as a quantity;
- density as a quantity
- pressure in fluids acts in all directions - including atmospheric pressure and pressure in water;
- fluids exert a force normal to a surface depending on the pressure and the area in contact: force = pressure x area
- pressure differences at a surface result in a net force normal to that surface; the net force is the pressure difference x area; this leads to an upwards force on the bottom of a wholly or partially submerged object;
- simple picture of the Earth's atmosphere and atmospheric pressure;
- pressure in a fluid; its magnitude related to depth and density;
- Archimedes principle;
- atmospheric pressure and height;

Appendix 1

Example uses of mathematics Opportunities to integrate mathematics in this section should include the following: A – Arithmetic ○ Finding net (resultant) collinear forces ○ Calculating weights, pressures, densities using simple proportional changes B – Data ○ SI units, SI prefixes (useful for measuring in a Hooke's Law experiment, various spring constants for comparison, pressures) C – Algebra ○ Make substitutions in the following equations: Weight – w=mg, Hooke's Law - F=kx, Pressure - P=F/A, Density – ρ = m/V, Pressure in a fluid – P=ρgh D – Graphs ○ Hooke's Law – Graphing F against x to find k, the spring constant E – Geometry ○ Diagrammatic representation of two coplanar forces
Example of developing physics ideas Opportunities to integrate the big ideas in physics into the content should include the following: • **Cause and effect**. Interactions cause forces on objects; forces can affect the shape of objects. • **Equilibrium**. Balanced forces; balanced pressures. • **Differences cause change**. A pressure difference results in a change of shape of movement; unbalanced forces cause change. • **Fields.** Gravitational, electric and magnetic fields • **models:** modelling forces; particle model of matter; simple picture of Earth's atmosphere; • **approximation and other techniques:** height of the atmosphere; weight of an object; • **Proportionality:** force exerted by a fluid and the pressure; force exerted by a fluid and the area; extension of a spring and the force it exerts; weight and mass of an object; weight and gravitational field strength;
Example of developing practical skills Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Forces and motion

Specifications and assessment schemes should ensure that students study:

Speed, velocity and acceleration

- Distance and speed and as quantities;
- displacement, velocity and acceleration as vector quantities;
- finding approximate values of speeds of, for example, walking, running, cyclists, sound;
- finding approximate values of some constant accelerations, including free fall;
- **motion in a circle (qualitative only); constant speed but changing velocity; centripetal acceleration (qualitative only) and the need for a centripetal force;**
- relative motion.

Distance-time and velocity-time graphs

- use and interpret graphs of distance and speed against time;
- use velocity-time graphs to determine displacement and acceleration;
- braking and stopping distances.

Equilibrium and balanced forces: Newton's 1st Law

- balanced forces;
- equilibrium and Newton's first law;
- uniform velocity in the absence of a net force.

Acceleration, force and mass: Newton's 2nd Law

- acceleration resulting from a net force on an object;
- mass (inertia) as the difficulty to accelerate an object (including from rest);
- Newton's Second Law: the relationship between acceleration, resultant force and mass;
- the dangers of large accelerations

Interactions and momentum: Newton's 3rd Law

- interacting objects; relating their change in motion to their mass;
- momentum as a vector quantity;
- interactions between pairs of objects produce equal and opposite forces on each of the objects: Newton's 3rd law
- interactions between pairs of objects produce equal and opposite changes of momentum; the principle of conservation of linear momentum;
- **conservation of momentum in collisions;**

Appendix 1

Example uses of mathematics
Opportunities to integrate mathematics in this section should include the following:
 	
A – Arithmetic
    o make calculations using ratios and proportional reasoning to convert units and to compute rates
B – Data
    o Use data in calculation of average velocity, speed and acceleration
C – Algebra
    o formulae relating distance, time and speed for uniform motion and for motion with uniform acceleration; calculate average speed for non-uniform motion;
    o apply formulae relating force, mass, velocity, acceleration and time to explore how changes involved are inter-related
    o **apply equations about conservation of momentum in collisions**.
D – Graphs
    o represent changes and differences using appropriate distance-time, velocity-time and acceleration-time graphs, and interpret lines, gradients and enclosed areas in such graphs

Examples of developing physics ideas • **Cause and effect**. *Net forces produce an acceleration, acceleration means change in velocity* • **Conservation.** *Conservation of momentum in collisions;* • **Equilibrium**. *Balanced forces result in no change in velocity* • **Differences cause change**. *Net forces produce acceleration* • **Dissipation.** *Work against friction causes temperature rises that heat the surroundings and are dissipative.* • **models:** *modelling forces through arrows and hence their use in free body diagrams,* • **approximation and other techniques:** *graphing v-t and s-t, area under the line, measuring gradient of a line* • **Proportionality.** *Acceleration is proportional to force; distance travelled is proportional to average speed (and time); change in velocity is proportional to accelerations (and time).*

Appendix 1

Wave properties and behaviour, the electromagnetic spectrum

Specifications and assessment schemes should ensure that students study:

Wave properties

- wavelength, frequency, amplitude, wave velocity, period;
- transverse and longitudinal waves;
- the relationship between speed, frequency and wavelength;
- measuring the speed of waves;
- waves carry information and energy;
- examples of waves and the differences and the similarities between them;
- interference patterns of sound and light as evidence of their wave nature;
- absorption and attenuation in a medium;
- **dispersion and colour;**
- **colour and differential absorption, transmission and reflection**
- **qualitative treatment of resonance.**

Reflection and refraction

- ray diagrams to illustrate reflection and refraction;
- reflection: the difference between specular and diffuse reflection, the laws of reflection; images in a plane mirror;
- refraction: change of direction and change of velocity, apparent depth;
- **refractive index and the relationship between angles of incidence and refraction.**

Lenses

- **converging and diverging lenses;**
- **ray diagrams; real and virtual images.**

The ear: audible and inaudible frequencies

- the structure of the ear and function of its parts;
- auditory range;
- safety issues.

Applications of waves

- **the use of waves to examine the structure of objects including the Earth and our bodies.**

Electromagnetic waves

- electromagnetic waves are transverse waves that can travel through space;
- polarisation as evidence of the transverse nature of light;
- travel from source to receiver at the same speed (speed of light) in a vacuum.

Regions and uses of the electromagnetic spectrum

- the main groupings of the spectrum;
- properties (absorption, transmission, reflection and refraction) and uses of different parts

of the spectrum;
- hazards associated with electromagnetic waves;
- **black body radiation: relating intensity and wavelength distribution to temperature (qualitative only).**

Example uses of mathematics

Opportunities to integrate mathematical ideas into the content should include the following:

A. Arithmetic and numerical computation

Determine the angle of refraction

Recognise and compare differences in wavelength and frequency across the electromagnetic spectrum, using standard form.

C. Algebra

Apply $v = f\lambda$, including where waves are refracted.

Apply $s = d / t$ to calculate the speed of sound.

E. Geometry and trigonometry

Draw ray diagrams of reflection and refraction.

Graphical addition of waves.

Example of developing physics ideas

Opportunities to integrate the big ideas in physics into the content should include the following:

- **Cause and effect**: an initial disturbance sets a wave off; at a detector, the wave will make something happen.
- **Differences cause change**. Difference in pressure are what propagate in a sound wave.
- **Dissipation:** absorption and attenuation of waves.

- **Models:** ray diagrams; use of a particle model in e.g. sound waves. The idea of waves as a general model.
- **Approximation and other techniques:** using typical values of frequency and wavelength for electromagnetic waves
- **Proportionality.** Wavelength is *inversely* proportional to frequency in, for example, the electromagnetic spectrum.

Example of developing practical skills

Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Electricity

Specifications and assessment schemes should ensure that students study:

Circuits, current and potential difference

- a model of electric current as the flow of charged particles;
- common circuit components;
- the need for a complete circuit and a source of potential difference for charge to flow;
- how the current in a component varies with potential difference across it;
- current and potential difference as quantities (see appendix 1);
- measuring potential differences and currents in circuits.

Resistance

- the effect of resistance on the current in a circuit;
- resistance as a quantity;
- ohmic and non-ohmic components; and compnents whose resistance changes with, for example, temperature or light level.

Series and parallel circuits

- currents and potential differences in series and parallel circuits;
- resistors in series (quantitative) and in parallel (qualitative only).

Electrical work

- electrical work and power as a quantities.

Domestic uses and safety

- **alternating and direct potential differences and currents;**
- nature of UK Domestic supply (230V AC 50Hz);
- live and neutral wires;
- electrical safety: for example fuses and earth wires; circuit breakers and RCDs.

Static electricity – forces and electric fields (first two bullets are KS3)

- charge as a property of some particles; charging objects by friction;
- charge as a quantity;
- forces between like and unlike charges;
- uses and dangers of static electricity;
- comparisons of static electricity and current electricity.

Appendix 1

<u>Example uses of mathematics</u>

Opportunities to integrate maths ideas in this topic should include:

C. Algebra
Select and use the equations relating potential difference , current, quantity of charge, resistance, power, energy, and time, and solve problems for circuits.

D. Graphs
Use graphs to explore whether circuit elements are ohmic or non-ohmic and relate the curves produced to their function and properties.

<u>Example of developing physics ideas</u>

- **Cause and effect:**
  A current flows when a source potential difference is put in a closed circuit.
  The effect of changing resistance on the current in a circuit.
  Non-ohmic components eg light levels affect resistance.
  Currents in resistors increase their temperature.
- **Conservation.**
  Conservation of charge
- **Differences cause change**.
  Difference in potential causes charge to move.
- **Dissipation.**
  Electrical work raises the temperature of resistors which then heat the surrounding.
- **Fields.**
  Electric fields surrounding charge.

- **models:**
  electron as a charged particle;
  current as flow of charge (in series and parallel)
- **approximation and other techniques:**
  choice of fuse
- **Proportionality.**
  current is proportional to source potential difference for constant R;
  current is *inversely* proportional to resistance (for constant V);
  Ohm's law

<u>Example of developing practical skills</u>

Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Magnetism and Electromagnetism

Specifications and assessment schemes should ensure that students study, explore deeply and understand ideas about:

*Permanent and induced magnetism (**much of this section is KS3**)*

- permanent magnets, induced magnetism and magnetic materials, including the domain theory;
- magnetic forces between unlike and like poles;
- the magnetic field of a magnet; measuring and representing its strength and direction;
- the Earth's magnetic field; the magnetic compass; magnetic reversals.

Magnetic effects of currents

- magnetic fields around current carrying wires including solenoids;
- factors affecting the field strengths;
- applications of electromagnets, e.g. recycling, MRI scanners, metal detectors.

The Motor Effect;

- the force between a current-carrying wire and a magnetic field;
- Fleming's left hand rule;
- the d.c. electric motor; its design and applications;
- other applications such as loudspeakers and earphones;
- the force on freely-moving charges in a magnetic field (qualitative only) and applications such as particle accelerators and the magnetosphere protecting us from solar wind.

Induced potential difference inducing a potential difference by changing the magnetic field;

- factors affecting the size and direction of the induced potential difference;
- structure of the a.c. generator;
- the transformer and other applications such as microphones.

National grid

- power stations and a.c.;
- transmission lines and reducing losses by stepping the potential up and down.

Uses of mathematics

Opportunities to integrate maths ideas in this topic should include the following:

C. Algebra A (arithmetic) and C (Algebra)

- apply the transformer equations and relate to the purpose of transformers in the national grid

Example of developing physics ideas

- **Cause and effect**.
  putting a current through a wire in a magnetic field will produce a force on it

changing magnetic fields induce pd across conductors.

- **Conservation.**
  conservation of energy in ideal transformers
- **Dissipation.**
  heating in transformers and transmission lines
- **Fields.**
  magnetic fields around permanent magnets and current carrying conductors

- **models:**
  Domain theory,
- **approximation and other techniques:**
  Ideal transformers
- **Proportionality.**
  Transformer equations

Example of developing practical skills
Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Particle model of matter

Physical changes and a particle model of matter

- heating a system will change the (internal) energy associated with the system raising its temperature or changing its state;
- specific heat capacity and specific latent heat;
- changes of state in terms of the arrangement and motion of particles and how these differ from chemical changes;
- the difference between boiling and evaporation;

Kinetic theory of gases

- pressure of a gas in terms of the random motion of its particles;
- the link between the temperature of a gas and the average speed of its particles;
- compression and expansion of gases by pressure changes;
- relationships between pressure, temperature and volume of a gas with one variable remaining constant (Boyle's, Charles' and Gay-Lussac's Laws); discussion in terms of particles;
- increasing the temperature of a gas by doing work on it;
- the concept of absolute zero.

<u>Example uses of mathematics</u>

Opportunities to integrate mathematics in this section should include the following:

C – Algebra

- the relationship between change in internal energy of a material and its mass, specific heat capacity and temperature change to calculate the energy change involved;
- the relationship between specific latent heat, the mass of a material, and the energy required to fully change its state;
- the relationship between pressure, volume and temperature with one variable kept constant.

D – Graphs

- finding absolute zero by graphical method.

<u>Example of developing physics ideas</u>

- **Cause and effect**.
  the cause of gas pressure is down to the motion of the particles in the gas; changing (internal) energy alters the state of matter of a substance
- **Conservation.**

This topic relies on conservation of mass

- **Differences cause change**.
  Differences in temperature result in one body heating another;
  Temperature differences result in the transfer of thermal energy;

- **models:**
  the kinetic theory model of matter explains the macroscopic behaviour of gases
- **approximation and other techniques:**
  the discovery of absolute zero
- **Proportionality.**
  P is proportional to absolute T; V is proportional to absolute T;
  P is inversely proportional to V;
  change in internal energy by heating and change in temperature.

<u>Example of developing practical skills</u>

Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Atomic structure

Specifications and assessment schemes should ensure that students study

Nuclear atom

- the nuclear model the atom, energy levels and line spectra;
- ionisation by the loss of electrons;

Isotopes and the nucleus

- the composition of the nucleus: protons and neutrons;
- elements and proton number; isotopes and nucleon number.

Nuclear radiation

- stable and unstable nuclei of different isotopes;
- emission of ionising radiations;
- the nature and properties of alpha, beta and gamma radiations.
- nuclear decay and changes in total mass;
- balanced nuclear equations for alpha and beta decay.

Half-lives

- background radiation;
- half-life and activity;
- radioactive decay as a random process;
- relating hazard to half-life and type of radiation.

Applications and risks of radioactive materials

- hazards associated with ionising radiations;
- hazards associated with contamination and ingestion of radioactive materials;
- usesand risks of nuclear radiation in medicine and industry.

Nuclear Fission and fusion

- some nuclei are unstable and may split (fission);
- stimulated fission and chain reactions in sustained fission reactions.
- nuclear fusion in stars; fusion reactors.

Example uses of mathematics

Opportunities to integrate mathematics in this section should include the following:

A Arithmetic
Balancing nuclear decay and fission / fusion equations

B
decay model experiments

C Algebra
calculate the age of a sample from half life and activity data

D Graphs calculation of half-life from decay graphs
<u>Example of developing physics ideas</u> • **Cause and effect**. Radiation causes damage to tissue • **Conservation.** Nucleon number and proton number in decay equations • **Differences cause change**. Difference in binding energy causing radioactive decay • **models:** Rutherford's atomic model
<u>Example of developing practical skills</u> **<u>Opportunities to integrate maths ideas in this topic should include: (to be added)</u>**

Appendix 1

Space physics

Specifications and assessment schemes should ensure that students study,:

Mass and weight

- the difference between mass and weight;
- all objects have the same acceleration in free fall.

Law of gravitational attraction

- gravitational field strength decreases with increasing distance from a mass;
- weight and gravitational field strengths on the surface of other bodies e.g. the Moon.

Solar system; stability of orbital motions; satellites

- **orbits and gravity; planetary orbits and the orbits of comets;**
- **period of orbits and orbital radius – related to weaker g and greater orbital path length;**
- **satellite orbits and the uses of satellites; geostationary satellites.**

Red-shift; the 'Big Bang' and universal expansion

- cosmological Red shift of distant galaxies as evidence of an expanding Universe;
- an expanding universe suggests the Big Bang Model.

Energy of the Sun and fusion

- nuclear fusion as an energy source in the core of a star;
- the stability of stars;
- life cycle of stars depending on initial mass.

Example uses of mathematics

D. Graphs

Plot a graph of g against r for different bodies

C Algebra

Use and rearrangement of $a = F/m$ and $w=mg$

Use $2\pi r/T = v$

Example of developing physics idea

- **Conservation.**
- **Equilibrium**.
  balanced forces in stars
- **Differences cause change**
- **Fields.**
  Gravitational fields
- **models:**
  simple model of life cycle of low mass and high mass stars

big bang theory, ▪ **Proportionality.** *Weight and mass; weight and gravitational field strength; gravitational field strength and mass.*
<u>Example of developing practical skills</u> Opportunities to integrate maths ideas in this topic should include: (to be added)

Appendix 1

Energy

Specifications and assessment schemes should ensure that students study:

Energy calculations

- the ways that the energy within a system can be changed:
  - doing work by forces,
  - doing electrical work,
  - heating;
- the energy associated with:
  - a moving body (kinetic),
  - a stretched or compressed spring (elastic potential),
  - raising an object (gravitational potential).

Conservation

- the conservation of energy
- the way that energy is stored in systems before and after a change.

Energy transfer and dissipation

- heating by particles (conduction) and by radiation;
- dissipation: an unavoidable consequence whenever heating occurs;
- reducing unwanted energy transfers;
- power as rate of transfer of energy;
- efficiency.

Energy resources

- quantifying national and global energy resources;
- renewable and non-renewable energy resources;
- patterns and trends in the use of energy resources.

<u>Example uses of mathematics</u>

Opportunities to integrate mathematics in this section should include:

C: Algebra

- Select and use equations relating to doing work by forces, doing electrical work, heating to produce a temperature change, efficiency, power
  select and use equations to determine an unknown quantity for a moving body, a stretched spring, raising an object

- Do calculations relating to; energy before and after a change in a system, energy resources

Appendix 1

Example of developing physics ideas

- **Differences cause change**.
  a temperature difference drives energy transfer
- **Conservation.** Conservation of energy: changes in a system produce no net reduction in the total energy it associated with the system
- **Fields.** Energy associated with changes in position in a field
- **Cause and effect**. Energy does not cause things to happen. Explanations include, for example, ideas about forces or differences. Calculations of energy tell you whether some events can happen.
- **Models.** Modelling energy as an accounting system.

- **Equilibrium**. Energy transfer tends to reduce temperature difference, maintaining a temperature difference requires transferring energy to a hotter body at the same rate as it is transferred from it to a colder one
- **Dissipation.** Some stores are more useful than others. Energy associated with the surroundings is less useful.
- **Approximation and other techniques**.
- **Proportionality.**

Appendix 1b. Quantities

There are a number of quantities that appear within the topic. Within a specification, the approach to each one should be similar. The specification should encourage a good understanding of the quantity and how it fits into the model under discussion. Additionally, specifications should require students to know the unit, its abbreviation and how to determine the quantity (from a quantitative definition). The definitions given are neither the full nor the formal definitions of the quantities; however, they are good enough at this level – even though it leads to some circularity.

Quantity	**Symbol**	**Unit**	**Abbreviation of unit**	**Relationship that allows us to determine the quantity (at this level)**
Force	*F*	newton	N	-
Weight	*w*	newton	N	w = m x g
Gravitational field strength	*g*	newton per kilogram	N/kg	-
Distance	*s*	metre	m	s = v_{av} x t
Speed	*v or u*	metre per second	m/s, ms^{-1}	v_{av} = s/t
Acceleration	*a*	metre per second per second	m/s/s, m/s^{2} , ms-^{2}	a_{av} = (v – u)/t
Momentum	*p*	kilogram metre per second	kgm/s	p= m x v
Pressure	*p*	newton per square metre	N/ m^{2}	f = p x A
Density	□	kilogram per cubic metre	kg/m^{3}	□ = m/volume
Potential difference	*V*	volt	V	V = W/Q
Current	*I*	amp(ere)	A	I = Q/t
Resistance	*R*	ohm	□	R= V/I
Electrical work	*W*	joule	J	W= V x Q
Charge	*Q*	coulomb	C	Q = I x t
Time	*t*	second	s	-
Wavelength	□	metre	m	-
Frequency	*f*	hertz	Hz	1/T, v/□□
Amplitude	*a*	metre	m	-
Period	*T*	second	s	1/f
Wave velocity	*v*	metre per second	m/s	v = f□□, v = s/t
Work	*W*	joule	J	W = F x d
Electrical work	*W*	joule	J	W = V x q
Power	*P*	watt	W	P = W/t

Appendix 1c. Equations in physics

(a) In solving quantitative problems, students should be able correctly to recall, and apply the following relationships, using standard S.I.Units:

distance travelled = average speed x time

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

momentum = mass x velocity

$$\text{force} = \frac{\text{change in momentum}}{\text{time}}$$

weight = mass x gravitational field strength

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

kinetic energy =1/2 x mass x velocity^2

change in elastic potential energy = ½ x spring constant x change in length^2

work done = force x distance moved in the direction of the force

energy transferred = power x time

$$\text{efficiency of any device or process} = \frac{\text{work done}}{\text{energy supplied}} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$= \frac{\text{useful power output}}{\text{power input}}$$

$$\text{change in length} = \frac{\text{force}}{\text{spring constant}}$$

$$\text{current} = \frac{\text{charge}}{\text{time}}$$

$$\text{current} = \frac{\text{potential difference}}{\text{resistance}}$$

power = potential difference x current = current^2 x resistance

Appendix 1

electrical work done = charge x potential difference

distance travelled by a wave = wave speed x time

wave speed = frequency x wavelength

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

force = pressure x area

(b) In addition, students should be able correctly to select from a list and apply the following relationships:

energy transferred by heating to produce a temperature change = mass x specific heat capacity x change in temperature

energy associated with a change of state = mass x specific latent heat

force on a conductor (at right angles to a magnetic field) carrying a current :

= magnetic field strength x current x length

$$\frac{\text{voltage across primary coil } (V_p)}{\text{voltage across secondary coil } (V_s)} = \frac{\text{number of turns in primary coil } (N_p)}{\text{number of turns in secondary coil } (N_s)}$$

$$\frac{V_p}{V_s} = \frac{\text{current in secondary coil } (I_s)}{\text{current in primary coil } (I_p)}$$

at constant temperature: pressure x volume (of a gas) = constant

pressure due to a column of liquid = height of column x density of liquid x gravitational field strength

energy = mass x [speed of light in a vacuum $]^2$

energy = Δm x [speed of light in a vacuum (c)$]^2$

Appendix 1d. Some physics ideas

- **Cause and effect**. *Events can be discussed and understood in terms of causes and effects: what makes things happen the way they do.*
- **Conservation.** *Some quantities (charge, mass/energy, matter & momentum) are conserved. These conservation laws lead to powerful restrictions on behaviour.*
- **Equilibrium**. *Equilibrium occurs when two or more external influences are in balance - balanced forces, balanced moments, balanced pressures, equal flows in and out.*
- **Differences cause change**. *For example temperature difference, pressure difference, potential difference, differences in concentration and unbalanced forces.*
- **Inertia**. *Things will tend to stay as they are (including moving at a constant speed) unless something causes them to change.*
- **Dissipation.** *Many processes have an element that is resistive and dissipative. Dissipation is a result of the tendency of a system to become more disordered.*
- **Fields.** *Action at a distance can be understood in terms of fields*

- **models:** *physicists develop models (often mathematical) of systems to make predictions of their behaviour in a variety of circumstances;*
- **approximation and other techniques:** *making back-of-the-envelope calculations to test the plausibility of ideas; using techniques that consider limiting or extreme cases;*
- **Proportionality.**

Appendix 1e. Mathematical ideas

Mathematics is integral to the sciences, allowing students to capture, understand and describe many scientific phenomena. It is a quantitative tool for understanding scientific ideas. The use of mathematics should be integrated into the content specifications and assessment in order to encourage an authentic experience of the sciences. The mathematical requirements in science Key Stage 4 must be coherent with mathematics Key Stage 4 assessment.

The following are the minimum mathematical requirements for biology, chemistry and physics. They are referenced within each section with, in some cases, additional exemplification.

A. Arithmetic and numerical computation
i. Recognise and use expressions in decimal form.
ii. Recognise expressions in standard form.
iii. Use ratios, fractions and percentages
iv. Make estimates of the results of simple calculations, without using a calculator
v. Use calculators to handle sin x, cos x, tan x where x is expressed in degrees

B. Handling data
i. Use an appropriate number of significant figures
ii. Find arithmetic means
iii. Construct and interpret frequency tables and diagrams, bar charts and histograms
iv. Understand the principles of sampling as applied to scientific data
v. Understand simple probability
vi. Understand the terms mean, mode and median
vii. Use a scatter diagram to identify a correlation between two variables
viii. Make order of magnitude calculations

C. Algebra
i. Understand and use the symbols: $=$, $<$, $<<$, $>>$, $>$, $\propto$, $\sim$
ii. Change the subject of an equation
iii. Substitute numerical values into algebraic equations using appropriate units for physical quantities
iv. Solve simple algebraic equations

D. Graphs
i. Translate information between graphical and numeric form
ii. Understand that $y=mx+c$ represents a linear relationship
iii. Plot two variables from experimental or other data
iv. Determine the slope and intercept of a linear graph
v. Draw and use the slope of a tangent to a curve as a measure of rate of change
vi. Understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate

E. Geometry and trigonometry
i. Appreciate angles
ii. Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects
iii. Calculate areas of triangles and rectangles, surface areas and volumes of cubes.

Appendix 2 Society of Biology feedback on the draft GCSE criteria for single and double award biology

These comments draw on responses from a cross-section of the Society's Member Organisations, individual members, teachers, academics and other relevant stakeholders.

General:

- Biology is a quantitative subject and we support the aim of making this more apparent in the GCSE criteria. We believe there may be scope to develop this even further, for example, by highlighting a broader range of mathematical activities or through the further exemplification of the math skills included (although it should be made clear to awarding organisations that these examples should not be seen as limiting). However, we also recognise that it is essential that the mathematical content is embedded within the biology content (and within the assessment items) so that it appropriately supports the biology, rather than delivered as a separate entity. It is important that due consideration is paid to this as the awarding organisations develop their specifications and assessment items, and that teachers delivering the new content receive adequate support to contextualise and embed the new mathematical requirements in their teaching.
- We have concerns about the inclusion of command words in every statement in the GCSE criteria. In many cases we do not feel that the inclusion of command words is helpful – for example, some are not the appropriate word and others have a narrowing effect on what can be specified and assessed that is not helpful. However, there are a few examples where we feel the command words 'earn their keep' – i.e. the statement is improved by the inclusion of a command word, for example, to highlight progression of understanding from KS3 or specify a higher order skill that must be captured in the specifications and assessments. Examples of these have been highlighted below (and if command words were removed from these statements, we would want to see the sentiment of the statements retained). We therefore advise that a full review of the command words is undertaken, to identify which words are appropriate and/or necessary and which might benefit from revision or removal.
- Whilst we acknowledge that biology is a quantitative subject, it is also very much a practical subject. Practical work is an integral and essential part of learning in the sciences that promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding. It is also a valuable means through which students both generate data and recognise the value of their mathematical skills in analysing their results. We therefore wish to see the addition of a section on 'the use of practical skills' (to include both procedural knowledge and technical and manipulative skills) under each topic, to highlight the practical skills appropriate to each topic alongside examples of activities. Again, it should be made clear to awarding organisations that these examples should not be regarded as limiting. Draft examples of what this might look like have been included below.
  Note: These examples represent the beginnings of a rough working draft, put together in a very limited amount of time – they are therefore not intended to be an exhaustive list of skills or practical activities. Biology is a dynamic subject at the front of scientific development; practical endeavours in both the specifications and the classroom should

aim to reflect this through introducing innovative and up-to-date activities where appropriate.

- We have undertaken work to compare the content in the biology GCSE criteria with the content published in the draft Key Stage 4 (KS4) programme of study in February 2013. This work highlights which areas of content present in the draft KS4 programme of study are absent, or covered in less detail, than in the draft GCSE criteria. We would be happy to share this work with the Department and/or drafters if useful.
- We have welcomed the engagement of the biology drafter with the bioscience community in the development of the content document. The Society of Biology has access to a wide range of valuable expertise through its members and member organisations.

Draft reformed biology GCSE criteria

Introduction

These GCSE subject criteria set out the knowledge, understanding, skills and assessment objectives common to all GCSE specifications in biology, chemistry, physics and combined double award science, so ensuring progression from key stage 3 national curriculum requirements and the possibilities for development into A level.

They provide the framework within which awarding organisations create the detail of the subject specifications.

Subject aims and learning outcomes

This document sets out the learning outcomes and content coverage required for GCSEs in the sciences. In subjects such as the sciences, where topics are taught in progressively greater depth over the course of key stage 3 and key stage 4, GCSE outcomes may reflect or build upon subject content which is typically taught at key stage 3. There is no expectation that teaching of such content should be repeated during the GCSE course where it has already been covered at an earlier stage.

GCSE study in the sciences provides the foundations for understanding the material world. Science is changing our lives and is vital to the world's future prosperity, and all students should be taught essential aspects of the knowledge, methods, processes and uses of science. These essential aspects should be studied in ways that help students to develop curiosity about the natural world, insight into how science works, and appreciation of its relevance to their everyday lives. The scope and nature of such study should be broad, coherent, practical and satisfying, and thereby encourage students to be inspired, motivated and challenged by the subject and its achievements.

GCSE specifications in the sciences should enable students to:

- develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics
- develop understanding of the nature, processes and methods of science, through different types of scientific enquiries that help them to answer scientific questions about the world around them

- develop and learn to apply observational, practical, modelling, enquiry and problem-solving skills, ~~both~~ in the laboratory, field and in other learning environments
- develop their ability to evaluate claims based on science through critical analysis of the methodology, evidence and conclusions, both qualitatively and quantitatively.

Comment [A1]: 'Field' should be explicitly mentioned to highlight the expectation that children should be getting out of the classroom and the lab.
'Other learning environments' could be interpreted to just mean a classroom. Practical skills via IT or other routes are not a substitute.

Overall, students should be helped to appreciate the achievements of science in showing how the complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas relating to the sciences which are inter-linked and are of universal application. Some of these apply across and between the three sciences, whilst others are given emphasis mainly in the separate subjects of biology, chemistry and physics. However, there are some ideas about science which have more general application, including the assumption that every effect has one or more causes and that accepted scientific explanations, theories and models are those that best fit the facts known at a particular time.

The content below also sets out the mathematical skills required for each science discipline. Awarding organisations should go up to, but not beyond, the mathematical requirements specified in GCSE Mathematics.

Subject content

Biology

Biology is the science of living organisms and their interactions with each other and the environment. The study of biology involves collecting and interpreting information about the natural world to identify patterns and relate possible cause and effect. Biological information is used to help humans improve their own lives and strive to create a sustainable world for future generations.

This content sets out the full range of content for GCSE biology and the biology component of the combined double award in science. Awarding organisations may, however, use ~~any~~ flexibility to increase depth, breadth or context within the specified topics or to consolidate teaching of the subject content.

Statements below in bold text apply only to GCSE specifications in single award biology. Statements in [square brackets] apply only to specifications in combined double award science.

Scope of study
GCSE specifications should require students to:

Cell biology
Prokaryotic and eukaryotic cells

- describe a cell as the basic structural unit of all organisms
- describe the main sub-cellular structures of eukaryotic cells (plants and animals) and prokaryotic cells

Appendix 2

- relate sub-cellular structures to their functions, ~~especially~~ **including** the nucleus/genetic material, plasmids, ~~endoplasmic reticulum~~, mitochondria, ~~ribosomes~~, chloroplasts and cell membranes
- **evaluate the impact of electron microscopy on our understanding of sub-cellular structures including the nucleus, plasmids, mitochondria, chloroplasts and ribosomes**
- (describe and) explain the aseptic techniques used in culturing ~~micro~~organisms.

Growth and development of cells

- **describe the cell cycle and** explain the importance of mitotic cell division in growth
- **explain how errors in mitotic cell division may result in the formation of cancer cells**
- describe cell differentiation
- relate the adaptations of specialised cells to their functions
- explain the importance of meiotic cell division in halving the chromosome number to form gametes.

Stem cells

- **recognise** [describe] the function of stem cells in embryonic and adult animals and meristems in plants
- discuss some of the issues concerning the uses of stem cells in medicine.

~~Transport in cells~~

- ~~describe and explain how substances are transported into and out of cells through diffusion, osmosis and active transport.~~

Cell metabolism

- explain the mechanism of enzyme action including the active site and enzyme specificity
- **~~recall~~ explain the difference between intracellular and extracellular enzymes**
- **recognise that cellular respiration is an exothermic reaction which ~~enables metabolic processes in cells~~ is continuously occurring in all living cells**
- ~~compare the processes of aerobic and anaerobic respiration~~ the chemistry of aerobic and anaerobic respiration
- describe some anabolic and catabolic processes in living organisms including the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, lipids and proteins
- explain that anabolism + catabolism = metabolism.

Use of mathematics

- demonstrate an understanding of number, size and scale and the quantitative relationship between units
- use estimations and explain when they should be used
- calculate surface areas and volumes of simple shapes
- calculate surface area : volume ratios
- understand and use percentiles and calculate percentage gain and loss of mass

Comment [A2]: Parts of this are this is too advanced for GCSE. At this stage, not all students will/have learn/learnt about the functions of each of these organelles (e.g. ribosomes), therefore it is difficult to link their structure to function. Suggest amending the list of structures.

Comment [A3]: 'Evaluate' implies an analysis of the pro's and con's. 'Describe' or 'explain' is more appropriate. Or remove the command word entirely.

Comment [A4]: Electron microscopy is becoming widely supplanted by more sophisticated confocal microscopy and modelling – make less proscriptive?

Comment [A5]: Why is this single award only? If all students need to know about structure/function, then should all students also be expected to know about advancements that have allowed us to determine the structure? Consider switching the order.

Comment [A6]: If this command word was removed there would be more flexibility to deliver this in different ways – e.g. as a practical, an explanation of the process, or an explanation of the importance of the process.

Comment [A7]: Why not organisms? Animal and plant cells are now routinely cultured - aseptic techniques are important for them too

Comment [A8]: Risks and benefits? Issues has a tendency to sound negative.

Comment [A9]: Move to the section on transport

Comment [A10]: What is the learning outcome? Is it to recall that enzymes are found inside and outside the cell? Or to recall their different roles? Or that they are required in very different quantities inside vs outside the cell? Suggest revising for clarification.

Comment [A11]: This is covered at KS3

Comment [A12]: Suggest this revision to help overcome the common misconception that plants photosynthesise in the day and respire at night, when they respire all the time.

Comment [A13]: This is covered at KS3. Suggest adding a statement on the chemistry instead (as in the draft KS4 Programme of Study)

Comment [A14]: Some introduction to the structure/function relationship of these molecules might also be helpful, so that students get the idea that molecules are chemically different and that this difference underpins uses/function. Consider adding an introduction to biological molecules to help provide more context to what follows (e.g. understanding enzyme ...

- carry out rate calculations for chemical reactions
- compare/measure growth rate changes
- calculate with numbers written in standard form.

Use of practical skills – examples
- collect and store materials and samples *(prepare slides for examination under a microscope)*
- make accurate and objective observations, unaided or using instruments, e.g. microscope *(microbiology investigations)*
- make accurate and precise measurements using analogue and digital equipment *(fermentation experiments and food tests)*
- prepare reagents, solutions and samples *(use aseptic techniques when culturing microorganisms)*
- assemble and use electrical and mechanical equipment eg water bath (*investigations into respiration or enzyme activity)*

Transport systems

Transport in cells
- describe and explain how substances are transported into and out of cells through diffusion, osmosis and active transport.

Transport systems in multicellular organisms
- explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area : volume ratio.
- [describe] **explain** some of the substances which require transporting into and out of living organisms, to include oxygen, carbon dioxide, water, dissolved food molecules, mineral ions and urea.
- ~~explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area:volume ratio.~~

Human circulatory system
- ~~describe~~ explain the human circulatory system
- relate the structure of the heart and the blood vessels to their functions
- recognise the main components of the blood as red blood cells, white blood cells, platelets and plasma and explain the functions of each.

Transport systems in plants
- **describe the structure of xylem and phloem and link these to their functions in the plant**
- **explain how water and mineral ions are taken up by plants, relating the structure of the root hair cells to their function**
- [state that plants have transport tissues called xylem and phloem]
- [recall that water and minerals are transported in the xylem and that the products of photosynthesis are transported in the phloem]

Comment [A15]: Could add context as examples – e.g. calculating magnifications using optical and electron microscopes

Comment [A16]: This also provides an opportunity to introduce concentrations (a concept many students struggle with), which would also link back to a new statement in the 'use of maths' section

Comment [A17]: Moved from the 'Cell biology' section

Comment [A18]: Re-order these statements – the need for transport systems should come first in this section

Comment [A19]: Suggest a different command word here. Also, the statement could be re-focused – e.g. onto the needs of the organisms (and why it is important that they transport these substances).

Comment [A20]: Should this be more specific to follow on from the 'cell metabolism' sub-section above?

Comment [A21]: This should be 'explain - students should understand a pressure model at this level

Comment [A22]: Could add a statement linking the gaseous exchange system (covered at KS3) to the circulatory system to offer further progression of ideas

Comment [A23]: Consider expanding this into a compare and contrast (e.g. xylem is dead and works by transpiration, phloem is a living osmotic system). Should also mention of phloem pressure to compare to heart generated pressure in humans in the sub-section above.

Comment [A24]: Consider adding a statement about fungal/plant mutualism – in this context relating to the increased surface area afforded the root by the fungal mycelium (which also gives an opportunity to link to a maths topic).

Comment [A25]: Consider adding the role of Casparian strip and endodermis to be consistent and complete

- explain the processes of transpiration and translocation, linking the structure of the stomata to their function
- predict the effect of a variety of environmental factors on the rate of water uptake by a plant, to include light intensity, air movement, and temperature.

Comment [A26]: Inclusion of a command word is limiting here (plus 'predict' is too complex in this context). Removal of the command word would allow flexibility for this to be incorporated as a practical to develop enquiry skills ('measure…'), a thinking scientifically statement ('predict…'), an explanation ('describe…'), or a recall statement ('recall…'). Or is 'predict' included in order to ensure that awarding organisations assess understanding at a higher level.

Use of mathematics

- calculate surface area : volume ratios
- use simple compound measures such as rate
- carry out rate calculations
- plot, draw and interpret appropriate graphs.

Comment [A27]: Could include examples of the range of graph expected

Use of practical skills – examples

- exercise and cooling curves
- collect and store materials and samples *(demonstrate the effect of a variety of environmental factors on the rate of water uptake by a plant, to include light intensity, air movement, and temperature)*
- make accurate and precise measurements using analogue and digital equipment *(use of heart rate monitors)*
- prepare reagents, solutions and samples (*dissection of plant or animal tissue*)

Health, disease and the development of medicines

Comment [A28]: This section is currently a bit muddled. Suggest re-ordering some of the statements/sections as below.

~~*Health and disease*~~

- ~~define health and disease.~~

Comment [A29]: Suggest removing this statement – or re-wording on a way that states that health is more than just the absence of disease.

Disease and the immune system

Comment [A30]: If the statement on health is removed then this section could be renamed.

- different types of disease – infectious and non-communicable diseases – and the interactions between them
- describe the role of the specific immune system of the human body in defence against disease.

Comment [A31]: Moved from the section on 'Infectious diseases'

Infectious diseases

- recall that bacteria, viruses, protoctista and fungi can cause infectious disease in animals and plants
- ~~show understanding of~~describe how infectious diseases are spread in animals and plants: (to include a minimum of one common infection, one plant disease, and sexually transmitted infections in humans including HIV/AIDS)
- describe the non-specific defence of the human body against pathogens
- ~~explain how the spread of infectious diseases may be reduced or prevented in animals and plants. To include a minimum of one common infection, one plant disease and sexually transmitted infections in humans including HIV/AIDS~~
- ~~**recognise and explain the difficulties of controlling infections in plants**~~
- recall that plant defence responses include physical (including leaf cuticle, the cell wall) and chemical (including antimicrobial substances)

Comment [A32]: Moved to the section on 'Health and the immune system'

Treating~~, curing~~ and preventing disease

Comment [A33]: Title doesn't match content – have suggested re-ordering

- describe the use of vaccines and medicines in the prevention and treatment of disease
- outline the discovery and development of new medicines, including preclinical and clinical testing
- explain how plant defence chemicals have been used in the development of new medicines
- explain how the spread of infectious diseases may be reduced or prevented in animals and plants. To include a minimum of one common infection, one plant disease and sexually transmitted infections in humans including HIV/AIDS
    - ~~**recognise and explain the difficulties of controlling infections in plants**~~

Non-communicable diseases

- explain that many human diseases are not caused by infectious agents and are multifactorial. These include heart disease, many forms of cancer~~cancers~~, stroke, some lung and liver diseases and diseases influenced by nutrition, including type 2 diabetes ~~and nutritional diseases~~
- describe and evaluate some different treatments for cardiovascular disease
- evaluate the effect of life style factors, such as exercise, diet, alcohol and smoking, on the incidence of ~~cardiovascular~~ non-communicable diseases, to include the analysis of data on local, national and global diseases.

Use of mathematics

- translate information between graphical and numerical forms
- plot and draw different types of appropriate graphs selecting appropriate scales for the axes
- calculate cross-sectional areas of bacterial cultures and clear agar jelly using πr^2

Use of practical skills – examples

Coordination and control

Nervous coordination and control in humans

- describe the structure of the brain, spinal cord, sensory and motor neurones and sensory receptors
- relate the structure of the brain, spinal cord, sensory and motor neurones and sensory receptors to their functions
- explain how the structure of a reflex arc is related to its function.
- **recognise the structure of the main parts of the eye and relate these structures to their functions in vision**
- **describe common defects of the eye and discuss how some of these problems may be overcome**
- **recognise the difficulties of investigating brain function and of repairing the brain and other parts of the nervous system.**

Hormonal coordination and control in humans

- [describe the principles of hormonal coordination and control by the human endocrine system]

Comment [A34]: E.g. morphine, aspirin, digoxin, artemisinin

Comment [A35]: Moved to the section on 'Preventing and treating disease'

Comment [A36]: This is covered by the statement above

Comment [A37]: Consider adding something about genetic predisposition to this sub-section, to link to the later section on 'Inheritance, variation and evolution'

Comment [A38]: Not always contracted as an NCD

Comment [A39]: Need to include more on NCD's as suggested. A major study reported in *The Lancet* by Murray, et al., earlier this year shows that the UK is lagging behind other comparable countries in Europe and elsewhere in confronting the consequences of a range of NCDs.

Comment [A40]: Command word helpful here in terms of requiring progression from KS3

Comment [A41]: To be added

Comment [A42]: Suggest adding 'Homeostasis' to this section.

Comment [A43]: Consider adding a statement about the need for control and coordination in organisms

Comment [A44]: Consider adding a statement on the effects of drugs (e.g. stimulants and depressants) on the nervous system

Comment [A45]: Some of this moves into homeostasis. Suggest splitting some of the statements as below

- **recognise some of the main organs of the human endocrine system exemplified by the pituitary gland, thyroid gland, pancreas, adrenal glands, ovaries and testes**
- **summarise the roles of thyroxine, adrenaline**,~~[explain how] insulin and glucagon [control blood sugar levels] in the body~~
- ~~compare type 1 and type 2 diabetes and explain how they can be treated.~~
- ~~*Hormones in human reproduction*~~
- explain the function of hormones in human reproduction, including the control of the menstrual cycle involving FSH, LH, estrogen and progesterone
- evaluate different methods of contraception
- explain the use of hormones in modern reproductive technologies to treat infertility.

Plant hormones

- explain the importance of auxins, **gibberellins and ethlyene** in the control and coordination of plant growth and development
- predict the effects of light and gravity on plant tropisms
- explain that some plant hormones are transported around the plant in the xylem and phloem
- describe some of the different ways in which people use plant hormones to control plant growth.

~~*Use of mathematics*~~

- ~~extract and interpret data from graphs, charts and tables~~

Homeostasis

- explain the importance of maintaining a constant internal environment
- explain the importance of removing the waste products of metabolism including carbon dioxide and urea
- [summarise the roles of the skin, the lungs and the kidneys in homeostasis and excretion]
- **summarise** [explain how] insulin and glucagon [control blood sugar levels] in the body
- compare type 1 and type 2 diabetes and explain how they can be treated.
- **explain the function of the skin in the control of body temperature**
- **predict the effect on cells of osmotic changes in extra cellular body fluids**
- **describe the function of the kidneys in maintaining the water balance of the body, explaining the effect of ADH on the permeability of the kidney tubules**
- **explain the response of the body to different temperature and osmotic challenges.**

Use of mathematics

- extract and interpret data from graphs, charts and tables
- translate information between numerical and graphical forms
- extract and interpret information from charts, graphs and tables.

Comment [A46]: This part of the statements may fit better under 'Homeostasis'

Comment [A47]: Delete this sub-heading and add the following bullets to the sub-section on 'Hormonal coordination and control in humans'

Comment [A48]: Leave this heading as 'plant hormones' or change to 'Hormonal coordination and control in plants' to match the similar heading for humans?

Comment [A49]: Add a statement on plant tropisms here (e.g. to encourage practical work). Alternatively, add 'including an explanation of phototropism, geotropism/gravitropism, dwarf plants and fruit ripening' to the previous statement.

Formatted: Font: (Default) Arial, Highlight

Comment [A50]: Consider moving this to the 'Transport' section, to link with the other statements on xylem and phloem. If retained here, then it should be the first bullet point in this sub-section.

Comment [A51]: Added to end of section (now that 'Homeostasis' has been incorporated.

Comment [A52]: Suggest making this a sub-section of 'Coordination and control' rather than a separate section.

Formatted: Font: (Default) Arial, 11 pt, Not Bold, Italic

Formatted: Font: (Default) Arial, Not Bold, Italic

Formatted: Font: (Default) Arial, 11 pt, Not Bold, Italic

Comment [A53]: Added from section on 'Hormonal coordination and control in humans'

Comment [A54]: Same for plants but with pressure changes because of cell wall

Comment [A55]: Moved below 'Homeostasis' from original 'Coordination and control' section

Comment [A56]: From original 'Homeostasis section

Appendix 2

Use of practical skills – examples

- collect and store materials and samples (*Demonstrate the effect of light and gravity on plant tropisms)*
- record qualitative and quantitative data (*demonstrate effects of variables on germination and growth rates)*
- make accurate and objective observations, unaided or using instruments (***demonstrate the effect on cells of osmotic changes in body fluids)***

Photosynthesis

Importance of photosynthesis

- state that light is needed for photosynthesis, recall the main reactants and products of photosynthesis and recognise photosynthesis as an endothermic reaction
- describe ~~plants and algae~~photosynthetic organisms as the main producers of food for life on Earth.
- the chemistry of photosynthesis

Factors affecting photosynthesis

- demonstrate the effect of light intensity on the rate of photosynthesis
- **predict the effect of temperature and carbon dioxide concentration on the rate of photosynthesis**
- evaluate the effect of long term changes in carbon dioxide levels, light intensity, water availability and temperature on photosynthesis.

Use of mathematics

- understand and use simple compound measures such as the rate of a reaction
- translate information between graphical and numerical form
- plot and draw appropriate graphs, selecting appropriate scales for axes
- **understand and use inverse proportion, the inverse square law and light intensity in the context of factors affecting photosynthesis**
- extract and interpret information from graphs, charts and tables.

Use of practical skills – examples

- assemble and use apparatus and glassware *(predict the effect of a variety of environmental factors on the rate of water uptake and the rate of photosynthesis by a plant)*
- record qualitative and quantitative data *(demonstrate the effect of light intensity, temperature and carbon dioxide concentration on the rate of photosynthesis, for example through the use of sensors)*
- collect accurate and continuous data

~~Material cycles~~

~~The principle of material cycling~~

- ~~recognise that many different materials cycle through the abiotic and biotic components of an ecosystem.~~

Comment [A57]: Consider adding a statement to this section (or the section on 'variation and evolution' about the importance of the of emergence of photosynthetic organisms (e.g. cyanobacteria) to evolution in terms of oxygen generation.

Comment [A58]: This part of the statement doesn't really build on what appeared in the KS3 programme of study on photosynthesis.

Comment [A59]: This part of the statement doesn't really build on what appeared in the KS3 programme of study on photosynthesis. Consider adding something on biomass to link to statements below?

Comment [A60]: Water availability is a more significant issue than light intensity

Comment [A61]: This does not warrant a separate section of its own. Suggest adding as a sub-section under 'Ecosystems'.

~~*The decomposers*~~

- ~~recognise that many microorganisms are decomposers~~
- ~~explain the role of microorganisms in the cycling of materials through an ecosystem~~
- ~~**explain the importance of nitrogen-fixing bacteria in root nodules**~~
- ~~describe the carbon cycle and explain its importance~~

~~**predict and explain the effect of factors such as temperature and water content on rate of decomposition**~~

~~describe the carbon cycle and explain its importance~~

- ~~analyse data on the changing distribution of organisms in response to climate changes~~
- ~~**evaluate the evidence for the impact of changes in atmospheric carbon dioxide levels on the distribution of living organisms.**~~

~~analyse data on the changing distribution of organisms in response to climate changes~~

Comment [A62]: Moved to section on 'Ecosystems'

- ~~*Use of mathematics*~~
- ~~calculate the rate changes in compost breakdown~~
- ~~calculate the percentage of mass change.~~

Comment [A63]: Moved down to section on 'Ecosystems'

Ecosystems

Levels of organisation within an ecosystem

- recognise the different levels of organisation from individual organisms to the whole ecosystem
- ~~the components of an ecosystem~~
- describe abiotic and biotic factors that affect communities
- explain the importance of interdependence and competition in a community.

Comment [A64]: Delete this statement as it is covered elsewhere in the sub-section on 'The principle of material cycling'

~~*Material cycles*~~

The principle of material cycling

- recognise that many different materials cycle through the abiotic and biotic components of an ecosystem.

Comment [A65]: Moved from separate section into 'Ecosystems'

The decomposers

- recognise that many microorganisms are decomposers
- explain the role of microorganisms in the cycling of materials through an ecosystem
- **explain the importance of nitrogen-fixing bacteria in root nodules**
- **predict and explain the effect of factors such as temperature and water content on rate of decomposition in aerobic, anaerobic and artificial environments**
- describe the carbon cycle and explain its importance
- **evaluate the evidence for the impact of changes in atmospheric carbon dioxide levels on the distribution of living organisms.**

Comment [A66]: Revised to add clarity – is this about factors affecting bacterial decomposition or respiration?

Comment [A67]: This section is a bit dis-jointed and would benefit from greater consistency. Suggest revising. Methane should be included here and before the climate change statement.

- analyse data on the changing distribution of organisms in response to climate changes.

Pyramids of biomass and transfer through trophic levels

- recognise trophic levels
- describe pyramids of biomass and deduce the sources of the loss of biomass between them
- **calculate the efficiency of energy transfers between trophic levels.**

Biodiversity

- carry out a field ~~nan~~ investigation into the distribution and abundance of organisms in an ecosystem and determine their numbers in a given area
- ~~explain what is meant by biodiversity and discuss the challenges~~
- recognise both positive and negative human interactions within~~with~~ ecosystems and their impact on biodiversity
- discuss benefits and challenges of maintaining local and global biodiversity.

Some of the biological challenges of increasing food yields using fewer resources

- **state reasons for the increase in global human population**
- **discuss the relationship between this increase and changing birth and death rates**
- discuss~~describe~~ possible biotechnological and agricultural solutions, including genetic modification, to the demands of the growing human population~~**describe possible biological solutions, including those using new biotechnologies, to the problems demands of the growing human population**~~**.**

Use of mathematics

- calculate the rate changes in compost breakdown
- calculate the percentage of mass change~~.~~
- calculation arithmetic means
- understand and use percentiles
- plot and draw appropriate graphs, selecting appropriate scales for the axes
- extract and interpret information from charts, graphs and tables.

Use of practical skills – examples

- make accurate and objective observations *(investigate distribution and/or abundance organisms using quadrats and transects, population growth, population modelling)*
- unaided or using instruments *(investigate distribution and/or abundance organisms using quadrats and transects)*
- record qualitative and quantitative data, describe and classify materials and change *(carry out a field investigation into the distribution and abundance of organisms in an ecosystem and determine their numbers in a given area, use a key to classify organisms from a range of habitats)*
- make accurate and precise measurements using analogue and digital equipment eg thermometer; stopwatch; pH, oxygen, carbon dioxide and temperature sensors

Comment [A68]: What is meant by this? Suggest revising to add more clarity on the learning outcome would be helpful. E.g. 'recognise the differences between the tropic levels of organisms within an ecosystem' or 'recognise the strengths and limitations of using a trophic level to classify organisms within an ecosystem'.

Comment [A69]: Or biomass?

Comment [A70]: The importance of maintaining diversity is covered at KS3, so presumably students would have already covered what biodiversity means at that level.

Comment [A71]: Benefits are covered at KS3. Could substitute benefits for challenges.

Comment [A72]: Food yields are only one part of the food security issue (food security is mentioned more explicitly in the draft KS4 Programme of Study).

Comment [A73]: These should be combined into one statement (otherwise more clarity is needed on the intended learning outcome for the first statement). Consider mentioning food security in this statement – e.g. 'Describe the biological factors affecting levels of food security' [growing human population, changing diets of wealthier populations, new pests/pathogens, environmental change, sustainability, cost of agricultural inputs [Note: agricultural inputs link to GSCE chemistry]

Comment [A74]: This statement would be further strengthened by emphasising the need for understanding the science of the risks and potential benefits.

Comment [A75]: Moved down from original 'Materials cycling' section

(demonstrate the effect of factors such as temperature and water content on rate of decomposition)

Inheritance, variation and evolution

Reproduction

- **recognise the advantages and disadvantages of asexual and sexual reproduction in animals ~~and~~ plants and fungi.**

The genome and gene expression

- describe DNA as a polymer made up of two strands forming a double helix
- recall that DNA is made from four types of nucleotides,; **each nucleotide consistings of a common sugar and phosphate group with one of four different bases attached to the sugar**
- describe the genome as the entire DNA of an organism
- explain the following terms: chromosome, gene, variant, dominant, recessive, homozygous, heterozygous, genotype and phenotype
- ~~explain~~ recognise that the genome interacts with the environment to influence the development of the phenotype.
- ~~explain the following terms: chromosome, gene, variant, dominant, recessive, homozygous, heterozygous, genotype and phenotype~~
- recognise how the genome influences the development of the phenotype of an organism,
- **~~to include~~ a simple treatment of protein synthesis**
- discuss the potential importance for medicine of our increasing understanding of the human genome.

~~Gene expression~~Inheritance

~~recognise how the genome influences the development of an organism, to include a simple treatment of protein synthesis~~

- explain ~~monogenic~~ single gene inheritance
- predict the results of single gene crosses
- recognise that most phenotypic features are the result of multifactorial rather than ~~monogenic~~ single gene inheritance
- describe sex determination in humans
- **describe the work of Mendel in discovering the basis of genetics and recognise the difficulties of understanding inheritance before the mechanism was discovered.**

Variation and evolution

- state that there is usually extensive genetic variation within a population of a species
- explain that all genetic variants arise originally through mutations, which ~~may~~ have a negative, neutral or positive effect on the organism
- explain that most genetic variants have no effect on the phenotype, some variants contribute to the phenotype and, rarely, a single variant will ~~control~~ determine an aspect of the phenotype

Comment [A76]: Alternatively, substitute for ‘organisms’

Comment [A77]: This section provides an opportunity to make a clearer link between genetic predisposition and non-communicable diseases

Comment [A78]: Add ‘gene expression’ to the title of this sub-section and move some of the statements from the next sub-section into here as suggested.

Comment [A79]: Substitute ‘explain’ for ‘recognise’. Explaining would require an advanced understanding of this concept, beyond what should be expected at GCSE.

Comment [A80]: Switch the order of the statements to improve clarity

Formatted: Font: 11 pt, Not Bold

Comment [A81]: This might need more work – what does the latter statement add? Suggest combining into one statement and making this double award – e.g. ‘**recognise that the genome, and its interaction with the environment, influences the development of the phenotype of an organism**’.

Comment [A82]: Moved from the (new) ‘Inheritance’ sub-section

Comment [A83]: Consider splitting these into two statements – combining into one statement implies that students have a mechanistic understanding of how the genome influences development, which is too advanced for GCSE

Comment [A84]: Much of this section is on inheritance. Re-naming would improve clarity and better align with the section title.

Comment [A85]: Moved into sub-section above on ‘The genome and gene expression’

Comment [A86]: Suggest adding this to help address the common misconception that all mutations are negative, when they could be neutral or beneficial.

Comment [A87]: This statement might benefit from segmenting for further clarity

Appendix 2

- describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species
- describe how evolution occurs through natural selection of variants best suited to their environment
- the impact of developments in evolutionary biology on classifications: the three domain model based on DNA analysis; the phenotype model of kingdom, phylum, class, order family, genus and species
- evaluate the evidence for evolution to include fossils and antibiotic resistance in bacteria
- describe the work of Darwin and Wallace in the development of the theory of evolution by natural selection and

explain the impact of these ideas on modern biology.

Selective breeding and genetic engineering

- describe the impact of selective breeding on food plants and domesticated animals
- describe the main stages of the process of genetic engineering
- explain some of the possible benefits and risks of using genetic engineering in modern agriculture and medicine
- recognise some of the practical and ethical issues of using genetic engineering in modern agriculture and medicine.

Use of mathematics

- understand and use direct proportions and ratios in genetic crosses
- understand and use the concept of probability in predicting the outcome of genetic crosses
- extract and interpret information from charts, graphs and tables.

Use of practical skills – examples

Comment [A88]: That? Problem with describe /explain

Comment [A89]: Consider adding this (lifted from the draft KS4 Programme of Study). This builds on the classification knowledge introduced at KS1-2. Consider referencing Linneaus in relation to the five kingdom model.

Comment [A90]: Put these together in the same statement

Formatted: Normal, No bullets or numbering

Comment [A91]: In relation to gene splicing? E.g. '…the process of gene splicing in genetic engineering'.

Comment [A92]: Add risks as well as benefits

Comment [A93]: Risk of repetition of single award biology content in the ecosystems section?

Comment [A94]: Suggest combining these statements into one – e.g. 'explain some of the possible benefits and risks, including practical and ethical considerations, of using genetic engineering in modern agriculture and medicine.'

Comment [A95]: To be added

Appendix 3

Appendix 3 Feedback from the Royal Society of Chemistry on the criteria for GCSE chemistry and the chemistry content of double award science

General:

- RSC has real concern over the split of the content for 'double award' versus 'separate' subjects 'Double award' content should be approximately 2/3 'triple award' and ideally a little less. There is some material, e.g concentration, that should be in the double award as it is an essential concept for any student of chemistry, rather than being included in the content for the separate award alone, and some material in the double, such as the allotropy of carbon that could be moved to chemistry GCSE. More careful scrutiny of the material, and the balance of the material, between the separate and double award is needed. It is also important that triple award doesn't just include the harder material as this is not its purpose. It is almost certain that the content specified here is such that teachers will have little flexibility in delivery
- The document should provide a sense of the key practical skills of chemistry – synthesis, analysis, characterization – and how these can be covered in each of the subsections. The key areas should also be those that are identified for assessment. We should avoid specific mention of eg preparation of ammonia based fertilisers because they give a false impression of what is important (at least it does currently as it is the ONLY preparation specified in the document)
- The document also should highlight the key mathematical skills for chemistry, eg scale, proportionality, graph plotting, data interpretation from figures and graphs, simple algebraic rearrangement, alongside the very useful lists of maths topics for each subsection. By highlighting key maths skills, appropriately balanced assessments can be made
- Command words need to be aligned between the subjects, the range of words adopted simplified, and their meaning consistent across the awards.

Appendix 3

Chemistry

Chemistry is the science of the composition, structure, properties and reactions of matter, understood in terms of atoms, atomic particles and the way they are arranged and link together. It is concerned with the synthesis, formulation, analysis and characteristic properties of substances and materials of all kinds.

This content sets out the full range of content for GCSE Chemistry and the chemistry component of the combined double award in science. Awarding organisations may however use any flexibility to increase depth, breadth or context within the specified topics or to consolidate teaching of the subject content.

Statements below in **bold text** apply only to GCSE specifications in single award chemistry. Statements in [square brackets] apply only to specifications in combined double award science.

Scope of study

GCSE specifications should require students to:

Atomic structure and the Periodic Table

A simple model of the atom, relative atomic mass, electronic charge and isotopes

- describe how and why the atomic model has changed over time
- describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with most of the mass in the nucleus
- recall relative charges and approximate relative masses of protons, neutrons and electrons
- calculate numbers of protons, neutrons and electrons in atoms and ions, given proton number and mass number of isotopes.

The principles underpinning the modern Periodic Table

- use the names and symbols of the first 20 elements, Groups 1, 7 and 0 and other common elements from a supplied Periodic Table to write formulae and balanced chemical equations
- relate the reactions of elements to the arrangement of electrons in their atoms and hence to their atomic number.

Properties and trends in properties of elements in Groups 1, 7 and 0.

- recall the simple properties of Groups 1, 7 and 0

- correlate observed trends in simple properties of Groups 1,7 and 0 with the electronic structure of the atoms and predict properties from given trends.

Properties of transition metals

- **state the general properties of transition metals (melting point, density, reactivity, formation of coloured ions with different charges and uses as catalysts) and exemplify these by reference to a small number of transition metals.**

The prediction of chemical properties, reactivity and type of reaction from position in the Periodic Table

- show understanding that the Periodic Table allows predictions to be made about how elements might react
- predict reactions and reactivity of elements from their positions in the Periodic Table.

Physical and chemical properties of metals related to their atomic structure and position in Periodic Table

- distinguish between metals and non-metals on the basis of their characteristic physical and chemical properties
- relate the atomic structure of metals and non-metals to their position in the Periodic Table.

Structure, bonding and the properties of matter

Different kinds of chemical bonds: ionic, covalent and metallic bonding

- distinguish between the nature and arrangement of chemical bonds in ionic compounds, simple molecules, and giant ~~molecular~~ covalent? structures and polymers
- explain chemical bonding in terms of electrostatic forces and describe the transfer or sharing of electrons
- appreciate the limitations of dot and cross diagrams as representations.

Chemical bonds and their arrangement in relation to properties of materials, ionic compounds, molecules, giant molecules, and metals

- explain how the different types of bonds, their strengths in comparison with intermolecular forces, and the ways they are arranged are related to the properties of the materials.

Comment [AH96]: This topic seems a stretch at GCSE. If included it should address how the properties of the transition metals determine their myriad of uses and economic importance

Comment [AH97]: More comment needed on the 'limitations of dot and cross diagrams' and what does ‘appreciate’ mean?

Appendix 3

States of matter and change of state in terms of particle kinetics, energy transfers and the relative strength of chemical bonds and intermolecular forces

- recall and explain the main features of the particle model in terms of the states of matter and change of state, distinguishing between physical and chemical changes
- explain the limitations of the particle model when particles are represented by inelastic spheres
- use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur
- use data to predict states of substances at given conditions.

Bulk and surface properties of matter including nanoparticles

- **show understanding of the principles of molecular recognition using a simple 'lock and key' model**
- **appreciate that bulk properties of matter result from macro structures of atoms, but the atoms themselves do not have these properties**
- **write 'nano' in standard mathematical form**
- **relate 'nano' to typical dimensions of atoms and molecules**
- **relate surface area to volume for different-sized particles and describe how this affects properties**
- **relate the properties of nanoparticulate materials to their uses**
- **consider the possible risks associated with some nanoparticulate materials.**

Allotropy of carbon

- explain the properties of diamond, graphite, fullerenes and graphene in terms of their structures and bonding.

Use of mathematics

- estimate size and scale of atoms and nanoparticles
- translate information between diagrammatic and numerical forms
- represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures e.g. allotropes of carbon
- interpret, order and calculate with numbers written in standard form when dealing with nanoparticles
- use ratios when considering relative sizes and surface area to volume comparisons.

Comment [AH98]: This list could be usefully reordered: the second and fifth bullet points are the two key ideas here and they should be in the double award. Of the remainder there is too much of a focus on nano, especially the 'writing of nano' in standard form (which is highly specific). Additionally, the concept of risk is nowhere else introduced so it seems decidedly out of place being introduced here. Indeed it would be much better to discuss the risk = hazard x exposure concept than risk associated with nano specifically.

The 'lock and key' concept seems out of place here – especially as drugs interacting with proteins is not covered anywhere

Comment [AH99]: This section could be usefully moved to separate award.

Appendix 3

Chemical changes

Chemical symbols and formulae

- use chemical symbols to write the formulae of elements and binary compounds, both covalent and with monoatomic and polyatomic ions
- deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa.

Chemical equations, including representations using simple half equations and ionic equations and state symbols

- use the names and symbols of common elements and compounds to write formulae and balanced chemical equations and half equations
- use the formulae of common ions to deduce the formula of a compound and write balanced ionic equations
- describe the physical states of products and reactants using state symbols (s, l, g and aq).

Reactions of acids

- recall that acids react with metals and carbonates and write equations predicting products from given reactants.

Definitions with reference to hydrogen and hydroxide ions

- recall that acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions.

Neutralisation reactions

- describe neutralisation as acid reacting with alkali to form a salt plus water
- recognise that aqueous neutralisation reactions can be generalised to hydrogen ions reacting with hydroxide ions to form water.

Comment [AH100]: Some sense that this all pertains to reactions in water, ie it is an intentionally limited approach to neutralization ie it doesnt cover reactions like $NH_{3(g)}$ + $HCl_{(g)}$ $\rightarrow$ $NH_4Cl_{(s)}$

Dilute and concentrated, weak and strong acids

- use and explain the terms dilute and concentrated (amount of substance) and weak and strong (degree of ionisation) in relation to acids.

The pH scale

- show the simple connection between hydrogen ion concentration and pH
- describe neutrality and relative acidity and alkalinity in terms of the effect of the concentration of hydrogen ions on the numerical value of pH (whole numbers only).

Comment [AH101]: Not clear what 'show' means here. Does this section need to identify where the pH scale comes from in the first place?

Appendix 3

Redox reactions (oxidation and reduction)

- explain oxidation and reduction in terms of loss or gain of oxygen and loss or gain of electrons.

D*isplacement reactions as redox reactions*

- recognise that displacement reactions are examples of redox reactions and identify which species are oxidised and which are reduced.

The reactivity series of metals as the tendency of a metal to form its positive ion

- relate the reactivity of metals with water or dilute acids to the tendency of the metal to form its positive ion
- deduce an order of reactivity of metals from experimental results.

Electrolysis of various molten ionic liquids and aqueous ionic solutions

- recall that metals (or hydrogen) are formed at the cathode and non-metals are formed at the anode in electrolysis using inert electrodes
- predict the products of electrolysis of binary ionic compounds in the molten state
- describe the origin of competing reactions in the electrolysis of aqueous solutions of ionic compounds.

Reactions at the electrodes

Comment [AH102]: Is this necessary here?

- describe electrolysis in terms of the ions present and reactions at the electrodes. Use of

mathematics

- arithmetic computation and ratio when determining empirical formulae, balancing equations and considering pH.

Energy changes in chemistry

Exothermic and endothermic reactions, including reaction profiles

- distinguish between endothermic and exothermic reactions on the basis of the temperature change of the surroundings
- draw and label a reaction profile for an exothermic and an endothermic reaction
- recognise activation energy from a reaction profile as the total energy needed to break bonds in reactant molecules
- calculate energy changes (ΔH) in a chemical reaction by considering bond making and bond breaking energies in kJ.

Comment [AH103]: Not clear what the relevance of this last bullet is for GCSE, unless it helps with understanding fuels – but I don't think it is used there?

Carbon compounds as fuels

- recall that crude oil is a main source of hydrocarbons as fuel
- appreciate that crude oil is a finite resource.

Chemical cells and fuel cells

- recall that a chemical cell produces an electrical ~~voltage~~ potential difference until the reactants are used up
- compare the advantages and disadvantages of hydrogen/oxygen and other fuel cells for given uses.

Uses of mathematics

- arithmetic computation when calculating energy changes
- interpretation of charts and graphs when dealing with reaction profiles.

The rate and extent of chemical change

Factors that influence the rate of reaction, including catalysts

- suggest practical methods for determining the rate of a given reaction
- interpret rate of reaction graphs
- describe the effect of changes in temperature, concentration, pressure, and surface area on rate of reaction
- explain the effects of changes in temperature, concentration and pressure in terms of frequency and energy of collision between particles
- explain the effects of changes in the size of the pieces of a reacting solid in terms of surface area to volume ratio
- describe the characteristics of catalysts and their effect on rates of reaction
- identify catalysts in reactions
- explain catalytic action in terms of activation energy
- recall that enzymes act as catalysts in biological systems.

Reversible reactions and the concept of dynamic equilibrium

- recognise that some reactions may be readily reversed by altering the reaction conditions and that dynamic equilibrium occurs when the rates of forward and reverse reactions are equal
- predict and explain the effect of changing reaction conditions (concentration, temperature and pressure) on equilibrium position.

Comment [AH104]: Also the use of petroleum as a feedstock and competition with use as a fuel could cause problems as resources dwindle

Comment [AH105]: Suggest replacing ‘voltage’ with ‘potential difference’ to keep this in line with the terminology used in physics

Comment [AH106]: This whole section should be bold if the title is bold

Comment [AH107]: Given that reactions can be reversible, there is a need to ensure that ‘reversibility’ is not a criterion for physical change. Mention of Le Chatelier’s principle. What does ‘explain’ mean at this level?

Appendix 3

Uses of mathematics

- arithmetic computation, ratio when measuring rates of reaction
- drawing and interpreting appropriate graphs from data to determine rate of reaction
- determining gradients of graphs as a measure of rate of change to determine rate
- proportionality when comparing factors affecting rate of reaction.

Organic chemistry

*Homologous series, including alkanes [and], alkenes **and alcohols***

- recognise functional groups and identify members of the same homologous series
- name and draw the structural formulae, using fully displayed formulae, of the first four members of the straight chain alkanes, alkenes **and alcohols**.

*Simple reactions of alkanes [and], alkenes **and alcohols***

- predict the formulae and structures of products of reactions (combustion, addition across a double bond **and oxidation of alcohols to carboxylic acids**) of other members of these homologous series.

*Addition **and condensation polymerisation***

- explain the basic principles of addition polymerisation **and condensation polymerisation** by reference to the minimum number of functional groups within a monomer, number of repeating units in the polymer, and simultaneous formation or otherwise of a small molecule
- deduce the structure of an addition polymer from a simple alkene monomer and vice versa.

Naturally-occurring and synthetic polymers, including DNA

- appreciate that DNA is a polymer made from four types of monomer called nucleotides and that each nucleotide consists of a common sugar and phosphate group with one of four different bases attached to each sugar
- appreciate that a knowledge of organic chemistry is necessary to understand the chemical properties of the vast array of naturally occurring and synthetic materials by reference to the generality of reactions of functional groups and the ability of carbon to form chains, rings and helices.

Comment [AH108]: Why are alcohols for the separate award? In some senses these are the more interesting of the three, because they begin to have functionality for reactions. Perhaps put alkenes, or alkanes to separate award. And given carboxylic acids are mentioned as an oxidation product of alcohols, do they need to be included here too?

Comment [AH109]: 'Appreciate' command words are meaningless

Comment [AH110]: The last bullet statement is very unclear. What can GCSE candidates be expected to do as a result of 'appreciating' this idea? What questions could they be expected to answer? Also, how does this relate to the coverage of carbohydrates, proteins and lipids in biology? The helices of DNA are not based on chains of carbon atoms. The rings in carbohydrates involve oxygen as well as carbon. I do not think that the implications of this statement have been thought through.

Appendix 3

Chemical analysis
Pure and impure substances - know what is meant by the purity of a substance, distinguishing between the scientific and everyday use of the term 'pure'. *Separation techniques for mixtures of substances, including filtration, crystallisation, simple distillation, fractional distillation, and chromatography in a variety of phases* - describe, explain and exemplify the processes of filtration, crystallisation, simple distillation, and fractional distillation - recall that chromatography involves a stationary and a mobile phase and that separation depends on the distribution between the phases - interpret chromatograms, including measuring Rf values - suggest suitable purification techniques given information about the substances involved. *Measurement of purity of substances* - distinguish pure from impure substances from melting point data - suggest chromatographic methods for distinguishing pure from impure substances. ***Identification of ions and gases by chemical and spectroscopic means*** - **describe tests to identify selected gases, including oxygen, hydrogen, carbon dioxide and chlorine, aqueous cations and aqueous anions** - **identify species from test results** - **interpret flame tests for metal ions, including the ions of lithium, sodium, potassium, calcium and copper** - **describe the advantages of instrumental methods of analysis (sensitivity, accuracy and speed)** - **interpret an instrumental result given appropriate data in chart or tabular form, accompanied by a reference set in the same form.** *Conservation of mass* - apply the law of conservation of mass - account for observed changes in mass in non-enclosed systems during a chemical reaction and explain them using the particle model.

Comment [AH111]: Having a 'Practical work' commentary at the end of the section would help place these into some contexts, eg the synthesis of aspirin.

Comment [AH112]: it could be a problem if these tests are only included in the separate science specification. For example, these tests might well be used to identify the products of common reactions of elements and acids, as well as the substances formed at the electrodes during electrolysis. It would be restrictive not to be able to ask about the use of gas tests in these contexts. These gas tests are often introduced at KS3. Awarding Organisations should be given more freedom to create meaningful specifications based on coherent topics by allowing some flexibility in how the content is allocated across double-award and separate sciences. constraints are embedded in the curriculum.

Appendix 3

The quantitative interpretation of balanced equations

- calculate relative formula masses of species separately and in a balanced chemical equation.

*Use of the mole in relation to masses of pure substances, **volumes of gases and concentrations of solutions***

- understand and use the definitions of the Avogadro constant (in standard form) and of the mole
- relate the mass of a given substance to the amount of that substance in moles and vice versa
- **use the molar gas volume at room temperature and pressure (assumed to be 24 dm^3) to relate molar amounts of gases to their volumes and vice versa, and to calculate volumes of gases involved in reactions**
- **relate the mass of a solute and the volume of the solution to the concentration of the solution**
- determine the stoichiometry of an equation from the masses of reactants and products including the effect of a limiting quantity of a reactant
- use a balanced equation to calculate masses of reactants or products.

Principles for determining the concentrations of solutions

- **relate the concentration of a solution in mol/dm^3 to the mass of a solute and the volume of solution**
- **relate the volume of a solution of known concentration of a substance required to react completely with a given volume of a solution of another substance of known concentration**.

Use of mathematics

- arithmetic computation, ratio, percentage and multistep calculations permeates quantitative chemistry
- calculations with numbers written in standard form when using the Avo~~a~~gadro constant
- change the subject of a mathematical equation
- provide answers to an appropriate number of significant figures
- convert units where appropriate particularly from mass to moles
- interpret charts, particularly in spectroscopy.

Comment [AH113]: CS - pleased to see that there is improved progression for students taking 'double award' science into A-level chemistry with the inclusion of topics such as moles in the 'double award' content

Comment [AH114]: These need to be in the double award. They are key ideas that everyone should know and understand

Appendix 3

Chemical and allied industries

The comparison of yield and atom economy of chemical reactions

- **calculate theoretical amount of product from a given amount of reactant**
- **from the actual yield of a reaction, calculate the percentage yield of a reaction product**
- **define the atom economy of a reaction**
- **calculate the atom economy of a reaction to form a desired product from the balanced equation**
- **select and justify a choice of reaction pathway to produce a specified product given appropriate data such as atom economy (if not calculated), yield, rate, equilibrium position.**

Fractional distillation of crude oil and cracking

- describe and explain the separation of crude oil by fractional distillation and the production of more useful materials by two methods of cracking.

Carbon compounds as feedstock for the chemical industry

- recall that crude oil is a main source of hydrocarbons as feedstock for the chemical industry.

Different methods of extracting and purifying metals with reference to the reactivity series and the position of carbon within it

- use the position of carbon in the reactivity series to explain the principles of industrial processes used to extract metals, including extraction of a non-ferrous metal
- explain why and how electrolysis is used to extract some metals from their ores
- evaluate alternative methods of extraction, such as bioleaching.

Production, properties and uses of alloys

- **relate the composition of some important alloys to their properties and uses.**

Causes of corrosion and their mitigation

- **identify the conditions for corrosion and explain how mitigation is achieved by creating a physical barrier to oxygen and water or by sacrificial protection.**

Comment [AH115]: There is nothing here about the pharmaceutical industry. Given the importance of organic chemistry I'd have thought that essential. Otherwise we are in danger of providing a very limited view of what chemistry is about. Also, it is not clear what the key principles are that we are trying to convey. Better to delineate them than eg two methods of cracking, corrosion .

Comment [AH116]: Need reference to unconventional fuels too, such as; tar sands, fracking?

Comment [AH117]: Why are TWO methods of cracking required? Doesn't one method get over the idea?

Comment [AH118]: It is not clear why the bullet point on rusting is included under chemical industry and not under redox chemistry?

Appendix 3

The balance between equilibrium position and rate in industrial processes

- explain the trade-off between rate of production of a desired product and position of equilibrium in some industrially important processes
- interpret graphs of reaction conditions versus rate
- relate the commercially used conditions for an industrial process to the availability and cost of raw materials and energy supplies, control of equilibrium position and rate.

Agricultural productivity and the use of nitrogen, phosphorus and potassium- based fertilisers

- **recognise the importance of the Haber process in agricultural production**
- **show understanding of the importance of nitrogen, phosphorus and potassium compounds in agricultural production**
- **recognise that the industrial production of fertilisers requires several integrated processes and a variety of raw materials**
- **synthesise an ammonia-based fertiliser.**

Ceramics, polymers and composites

- compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals
- select appropriate materials given details of usage required, relating uses to properties.

The efficacy of life-cycle assessment ~~recycling~~

- describe the basic principles in carrying out a life-cycle assessment of a material or product
- interpret data from a life cycle assessment of a material or product
- describe a process where a material or product is recycled for a different use, and why this is viable
- appreciate why some materials or products cannot be recycled and recycling others is not economically viable.

Use of mathematics

- **arithmetic computation when calculating yields and atom economy.**

Comment [AH119]: This last point is far too specific, and being the only example of a synthesis, provides an imbalanced view of synthesis across the awards. The command word 'show' is unsuitable. How will students be expected to 'show' this?

Comment [AH120]: There must be some coordination between the maths requirements expected of students in science and those taught in maths e.g. in maths, students learn how to calculate say 25% of £100 or if the interest rate is 1.5% pa, they can work out how much interest they would make. However they do not need to do the calculation the other way round e.g. if you get £1.50 interest on £2000 invested what is the % interest. This means they cannot do percentage yields. Also maths students rarely need to draw their own graph axes and so struggle with deciding on a suitable scale when presented with a piece of graph paper on which to plot their results in science.

Earth and atmospheric science

The composition and evolution of the atmosphere since its formation

- show understanding of the evidence for how it is thought the atmosphere was originally formed and how it has changed over time.

Carbon dioxide and methane as greenhouse gases

- understand the greenhouse effect in terms of the interaction of radiation with matter
- recognise the causes of change in Earth's climate over geological timescales before the industrial period
- describe and analyse the evidence for additional anthropogenic causes of climate change, including changes in the Earth's orbit, changes in the atmosphere, the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels, and show an appreciation of the uncertainties in the evidence base
- describe the potential effects of climate change.

Comment [AH121]: NB Changes in the Earth's orbit is not 'anthropogenic!

Carbon capture and storage

- show understanding of the principles of carbon capture and storage to reduce atmospheric levels of carbon dioxide
- compare and contrast industrial processes for carbon capture and storage with the carbon cycle and naturally occurring processes in the oceans, including consideration of scale and environmental implications.

Comment [AH122]: RO: Consider the potential & consequences of a large-scale release of carbon dioxide from a carbon capture & storage site underground

Common atmospheric pollutants and their sources

- recognise the major sources of carbon monoxide, sulfur dioxide, oxides of nitrogen and particulates in the atmosphere and the problems caused by increased amounts of these.

The Earth's water resources and obtaining potable water

- describe the effects of human activity and increased population on the availability of potable water
- describe the principal methods for making water potable in terms of the separation techniques used, including ease of treatment of waste, ground and salt water.

<u>Use of mathematics</u>

- extract and interpret information from charts graphs and tables
- use orders of magnitude to evaluate the significance of data.

Appendix 3

Working scientifically

Biology, chemistry, physics and double award combined science

1. Development of scientific thinking	• be objective, and have concern for, accuracy, precision, repeatability and reproducibility • understand how scientific methods and theories develop over time • recognise the importance of publishing results and peer review • appreciate the power and limitations of science and consider any ethical issues which may arise • evaluate risks both in practical science and the wider societal context, including perception of risk in relation to data and consequences.
2. Experimental skills and strategies	• use scientific theories, models and explanations to develop hypotheses • plan experiments to make observations, test hypotheses or explore phenomena • apply a knowledge of techniques, apparatus, and materials to select those appropriate to the experiment and use them appropriately, having due regard to health and safety considerations • apply a knowledge of sampling techniques to ensure any samples collected are representative of the whole population • make and record observations and measurements using a range of methods • evaluate methods and suggest possible improvements and further investigations.

Comment [AH123]: There is nothing here that highlights the key chemistry ideas of synthesis, analysis, and characterisation

3. Analysis and evaluation	- apply the cycle of collecting, presenting and analysing data, including:
	  - present observations and data using appropriate methods
	  - carry out and represent mathematical and statistical analysis
	  - represent random distributions of results and estimations of uncertainty
	  - interpret observations and data, including identifying patterns and trends, make inferences and draw conclusions

	- present reasoned explanations including of data in relation to hypotheses
	  - evaluate data
	  - use an appropriate number of significant figures in calculations
	- communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations.

4. Units, symbols and nomenclature	- use SI units (e.g. kg, g, mg; km, m, mm; kj, j), IUPAC chemical nomenclature - use prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, milli, micro and nano) - interconvert units.

Examples from biology

1. Development of scientific thinking	- all quantitative biology - the development of genetics, the theory of evolution - evaluation of methods for treating cardiovascular disease, changing distribution of organisms - reproductive technologies, use of stem cells in medicine, use of the human genome, maintaining biodiversity, sustainable food supplies - impact of genetically engineered organisms - vaccine safety.

2. Experimental skills and strategies	• predict the effect of a variety of environmental factors on the rate of water uptake and the rate of photosynthesis by a plant • exercise and cooling curves • microbiology investigations • investigate distribution and/or abundance organisms investigations into respiration or enzyme activity • enzyme investigations.
3. Analysis and evaluation	• any experimental report • appropriate use of mean values, determination of outliers etc.
	• use of standard deviation in group results • recognition of the accuracy of laboratory equipment and summation of errors to give the range of a result • spread of infectious diseases in humans and plants • changes in distribution of organisms • reports of investigations and experiments.
4. Units, symbols and nomenclature	• size of cells and organelles, rate of growth of microbes • magnification in terms of light and electron microscope.

Examples from chemistry

Comment [AH124]: The examples here are not particularly helpful, and in some cases are far too specific (eg fertilizer synthesis, products of electrolysis, three relating to reaction rates, giving a somewhat unbalanced view of the relative importance

1. Development of scientific thinking	• All quantitative chemistry, e.g. determining the stoichiometry of a reaction • structure of the atom, the Periodic Table • discoveries of fullerenes and graphene • atmospheric science, nanoparticles • use of nanoparticulate materials.

2. Experimental skills and strategies	- predict the products of electrolysis - measurement of rates of reaction - preparation of fertilisers - selecting appropriate methods for measuring rates of reaction - measurement of common atmospheric pollutants - identification of ions and gases - comparison of methods for measuring rates of reaction.
3. Analysis and evaluation	- any experimental report - appropriate use of mean values, determination of outliers etc - recognition of the accuracy of laboratory equipment and summation of errors to give the range of a result - climate data - patterns and trends in the Periodic Table - consider uncertainties in climate data
	- relate quantitative answers to the accuracy of the measuring instruments - reports of investigations and experiments.
4. Units, symbols and nomenclature	- naming organic compounds - the Avogadro constant, nanoparticles.

Comment [AH125]: there is a heavy reliance on examples from rates of reaction (3/7)

Examples from physics

1. Development of scientific thinking	- structure of the atom, the Periodic Table - expanding universe and the Big Bang - uses of fission and fusion - risks with the uses of radioactive material.
2. Experimental skills and strategies	- test whether resistance is independent of current, or whether spring constant is independent of extension - design a domestic mains circuit based on a single fuse plug to maximise lighting intensity - measure the range and distribution of the walking and running speeds of students in a school class

Appendix 3

3. Analysis and evaluation	• estimate rates of deceleration of a range of vehicles on urban roads and use these to calculate the forces needed to produce these changes • explore how the current in a d.c. circuit varies with the potential difference across the battery terminals • write a report on an investigation for their parents or for students in another class
4. Units, symbols and nomenclature	• convert kilowatt hours to energy in joules • compare the power used to heat a room with that used to carry a heavy box upstairs.

Appendix 3

Assessment objectives

	Assessment objectives	Weighting
AO1	**Knowledge with understanding** **Recognise, recall and show understanding of:** • scientific phenomena, patterns, laws, theories and models • how scientific theories develop over time and are tested • scientific vocabulary, terminology, definitions, units and conventions • uses of scientific instrumentation and apparatus • scientific quantities and their determination • everyday and technological applications of science with their personal, social, economic and environmental implications • working safely in a scientific context.	30%
AO2	**Application, analysis, evaluation and problem solving** **The skills and abilities to:** • extract data relevant to a particular context from information presented in verbal, diagrammatic, graphical, symbolic or numerical form • translate data from one form to another • evaluate qualitative and quantitative data, carry out calculations as appropriate, recognise patterns in such data, draw conclusions and formulate hypotheses • explain familiar facts, observations and phenomena in terms of scientific laws, theories and models • present reasoned scientific explanations of unfamiliar facts and phenomena, and unexpected observations • apply a knowledge of sampling techniques to ensure any samples collected are representative of the whole population • apply scientific principles and formulate and justify methods to solve qualitative and quantitative problems • make decisions based on the evaluation of evidence and arguments • communicate scientific observations, ideas, arguments and	50%

Comment [AH126]: This AO carries too much weight and should be split into two – application and analysis, and evaluation and problem solving. The current AO has the strong potential to result in imbalanced assessments focusing on only a few of the skills and abilities rather than the full range

	conclusions logically, concisely in verbal, diagrammatic, graphical, numerical and symbolic form • explain everyday and technological applications of science and evaluate associated personal, social, economic and environmental implications • evaluate risks in a wider societal context • recognize that the pursuit of science is subject to practical constraints, theoretical uncertainties and ethical considerations.	
AO3	**Experimental skills and methods amenable to indirect assessment** **The experimental skills and abilities to:** • select or formulate propositions amenable to experimental test • devise procedures and select apparatus and materials suitable for synthesising substances or producing or checking the validity of data, conclusions, generalizations and hypotheses • recognise and explain variability and unreliability in experimental measurements • evaluate quantitative and qualitative data acquired through practical work, the design of experiments and experimental observations, draw conclusions and suggest improvements where appropriate.	10%
AO4	**Experimental skills and methods requiring direct assessment** **The ability to:** • follow instructions accurately • use scientific instrumentation, apparatus and materials appropriately • work with due regard for safety, managing risks • observe, measure and record accurately and systematically • carry out and report on investigations or parts of investigations.	10%

Comment [AH127]: This section should assess technical skills, while current AO3 can assess procedural skills

Appendix 4. Feedback from the Association for Science Education on GCSE subject content and assessment objectives.

GCSE SCIENCE Subject Content

Science subject aims and learning outcomes

The ASE welcomes the statement that specifications should enable students to develop and apply observational, practical, modelling, enquiry and problem-solving skills.

However, we are concerned that fieldwork is not mentioned specifically as a teaching and learning approach, either in the overall subject aims for science or in the introductions and subject content in the separate sciences. Fieldwork was mentioned in previous draft versions and is a requirement in the subject criteria for GCSE biology which are currently applied. The ASE recommends that fieldwork is reinstated, as a requirement across all science teaching. Without this it is likely that 'Outdoor Science' will continue to decline (a trend which was evidenced by our own survey of 388 science teachers across all science disciplines, presented to the 2011 Science & Technology Committee inquiry into *Practical experiments in school science lessons and science field trips*). We are concerned that any decline in fieldwork will reduce opportunities to explore and teach inspirational science, including in local contexts that have clear links to everyday lives.

Recommendation

The ASE recommends that the third bullet is amended, to read:

- **develop and learn to apply observational, practical, modelling, enquiry and problem-solving skills, in the laboratory, ~~through~~ field ~~work~~ and ~~in~~ other learning environments.**

Biology subject content

ASE is concerned that fieldwork is not required explicitly in the biology subject content. Considerable evidence demonstrates that any presumption that fieldwork will be adopted as one of the 'other learning environments' is flawed. ASE recommends that the need for fieldwork should be stated explicitly in (at least) the Ecosystems section. For example, the introductory bullet in the Biodiversity sub-section should be amended to read:

- **Carry out a fieldwork investigation into the distribution and abundance of organisms in an ecosystem and determine their numbers in a given area.**