Appendices to accompany SCORE's response to the Department for Education Consultation on proposed GCE AS and A-Level Subject Content for Biology, Chemistry, Physics and Psychology

20 December 2013

The appendices that follow have been compiled by individual SCORE organisations, with contributions from their members and committees.

Appendix 1: General comments on the content requirements and working scientifically

Introduction

1. These content requirements set out the proposed knowledge, understanding and skills for AS and A level Biology, Chemistry, Physics and Psychology.

Aims and objectives

2. AS and A level specifications in a science subject must encourage learners to:

- develop essential knowledge and understanding of different areas of the subject and how they relate to each other;
- develop and demonstrate a deep appreciation of the skills, knowledge and understanding of scientific methods;
- develop competence and confidence in a variety of practical, mathematical and problem solving skills;
- develop their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject; and
- appreciate how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society.

Subject content

3. AS and A level Science specifications must build on the skills, knowledge and understanding set out in the *GCSE Criteria* for each Science.

4. The skills, knowledge and understanding set out in the appendices for AS in each science subject must comprise approximately 60 per cent of AS specifications. The skills, knowledge and understanding for A level must comprise approximately 60 per cent of an A level specification.

5. The remainder of both AS and A level specifications allows both for:

- further consideration of applications and implications of science and the development of scientific ideas; and

- the introduction of different areas of study.

Comment [A1]: This is very open. It would be a shame if recall-heavy topics were introduced into A-level physics.

6. AS and A level specifications must include a range of contemporary and other contexts.

7. AS and A level specifications must require learners to cover the areas of the subject as illustrated in the relevant appendix

8. The skills, knowledge and understanding of each specification in the subject must, where appropriate, include the requirements set out below, and be integrated into the mandatory content indicated in the relevant

appendix and any content added by the awarding organisation where appropriate:

- Use theories, models and ideas to develop scientific explanations.
- Use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas.
- Use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems.
- Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.
- Analyse and interpret data to provide evidence, recognising correlations and causal relationships.
- Evaluate methodology, evidence and data, and resolve conflicting evidence.
- Appreciate that scientific knowledge and understanding develops over time.

Comment [A2]: How would you assess this? What would count as evidence that a student 'appreciated' this?

- Communicate information and ideas in appropriate ways using appropriate terminology.
- Consider applications and implications of science and appreciate their associated benefits and risks.

Comment [A3]: Again what does 'appreciate' mean here – and how might this be assessed?

- Consider ethical issues in the treatment of humans, other organisms and the environment.

Comment [A4]: 'Consider' is vague. How might this be assessed?

- Appreciate the role of the scientific community in validating new knowledge and ensuring integrity.

Comment [A5]: Again, how would this be assessed? What would a student who 'appreciated' this be able to do that a student who did not appreciate it could not do?

- Appreciate the ways in which society uses science to inform decision making.

Comment [A6]: How does society use science to inform decisions? What are these 'ways'?
And comment 4 applies again.

9. Development of the skills, knowledge and understanding of each science subject must include the requirements for Working Scientifically set out in

Appendix 5 and the mathematical requirements for the relevant discipline set out in appendix 6.

Appendix 1

Working Scientifically

In order to be able to develop their skills, knowledge and understanding in science, learners need to develop the following key skills and behaviours. Specifications must encourage these through opportunities for regular hands on practical work.

Confidence and a positive attitude	Confidence in the lab or field
	Gaining experience in using practical equipment.
	Follow written instructions
	Engagement in own learning, willingness to learn
	Willingness to learn from mistakes
Independent thinking	Solving problems in a practical context
	Applying accuracy and judgement in practical work
	Applying theoretical knowledge to practical contexts
	Adopting a questioning and enquiring approach to practical work
Appreciation and application of scientific methods and practices	Consideration of scientific methodology including effective experimental design
	Making and recording observations
	Keeping appropriate records of experimental activities
	Managing time effectively in the lab Paying attention to both process and outcome of experiment
	Drawing conclusions and evaluating results with reference to measurement uncertainties and errors.
	Scientific writing skills An awareness of how scientific knowledge is shared in the scientific community

Comment [A7]: Not clear how this could be assessed

Comment [A8]: Ditto

Comment [A9]: Ditto

Comment [A10]: Meaning? How assessed?

Comment [A11]: How would this be assessed?

Comment [A12]: Is 'appreciation' assessable?

Comment [A13]: 'Methodology' is the study of methods. So what does this actually mean?

Comment [A14]: How might this be assessed?

Comment [A15]: Ditto

Comment [A16]: This is supposed to be a list of 'skills', so the word 'developing' should not appear here.

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Comment [A17]: How might this be assessed?

Appendix 1

	Evaluating experiments and experimental design
Numeracy and the application of mathematical concepts in a practical context	Identifying variables including those that must be controlled.
	Sense-checking quantities and results
	Analysing data
	Plotting graphs
	Interpreting graphs
	Using units, powers and logarithms appropriately
	Using statistics appropriately
	Considering margins of error, and accuracy and precision of recorded data in experiments.
The ability to work safely	Awareness and use of safe practices
	Understands potential risks, but does not fear apparatus/materials
IT skills	Using appropriate software and tools to collect and process data, carry out research and report findings.
Research and referencing	Using online research skills in order to support experiments
	Using offline research skills including textbooks and other printed scientific sources of information
	Correctly citing sources of information and avoidance of plagiarism
Instruments and equipment	Experiencing a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Comment [A18]: This seems to repeat the first point in this category.

Comment [A19]: Rather broad.

Comment [A20]: Is the latter part assessable?

Comment [A21]: This whole section reads like a 'wishlist' rather than a serious attempt to specify assessable 'skills' (i.e. 'practical capabilities' – things students can do).

Appendix 2: Institute of Physics overview and scope of content

Timing and opportunities for linking with mathematics

It is impossible to make a complete and final choice for the content of physics A-level without knowing what the mathematical background of the students is going to be. This is partly about the detail of what they have studied up to that point (in the revised GCSEs). However, there is a major issue of whether all post 16 students will take a mathematics qualification to support their studies. If this were to be the case in physics, it opens up the possibility of including ideas from calculus in Year 13 (see calculus section below). There is an opportunity to create a coherent and mutually supportive route for physics with mathematics. To do so requires more discussion and development than is possible in a short consultation and a hurried implementation of content for 2015.

Recommendation: we strongly recommend that the content is developed in conjunction with the requirements and content for mathematics at core, AS and A-level in the sixth form and that the reforms are aligned with changes to GCSE.

Overview and scope of content

The choice of content for physics looks about right. The statements are quite general – which is appropriate for this document. The content covers most of the topics that we would expect to be covered at AS and A-level and the amount of content looks appropriate to define 60% of the award. However, the content is quite dry and traditional in its look.

We do not propose adding significantly to the existing criteria for defining the core 60% of specifications. However, there are some areas that are not covered. These include statics, collisions in 2D, a.c. electricity, geometrical optics, thermodynamics (energy and entropy) and cosmology. The first four of these could be seen as core to A-level and the fifth and sixth have, in the past, been treated well in some A-level courses. There is a case to be made for including them in the criteria so long as the core is extended beyond 60%.

Recommendation: consider extending the core to at least 70% and including the first four topics above.

The document provides criteria to awarding organizations on how to make up the remaining 40% of content (paragraph 5). These top-up criteria are quite broad – especially the third bullet: *introduction of different areas of study*. This leaves open the possibility of Awarding organizations introducing topics in, for example, particle physics or cosmology that will require a lot of recall without adding any new ideas about physics. Such topics have often been treated superficially – the underlying physics being beyond A-level – and such treatments are better avoided. That is not to say that these topics might not be appropriate but they would need to be developed in a meaningful way so that they are rich – developing ideas and skills beyond recall.

Recommendation: It would be helpful to ensure that the 40% is not made-up with new topics that are mainly recall-based. The new content should be demonstrably rich.

Although the specified content is appropriate for A-level physics, it appears to be very dry as it stands. Again, it would be possible for the criteria to put an expectation on awarding organizations to use the remaining 40% to develop topics and content that develop some modern physics ideas and applications. For example, a topic on particle accelerators would bring together many aspects of traditional physics (forces, motion, electromagnetism, frames of reference) in a modern context. Similarly, cosmology, medicine, bio-physics, computational physics (including climate) and others can all be used as synthesis topics for traditional physics in modern contexts.

Recommendation: Awarding organizations should be expected to use the 40% to synthesis topics that bring together the existing content and some unifying themes in modern contexts.

Specific comments

The accompanying file has some specific comments about the way the content is expressed and placed. For example, Newton's laws of motion should not have a special place outside the topics – they should be in the mechanics topic. There are three expressions used for voltage (voltage, potential difference and EMF) without any clear distinction between them.

Recommendation: review specific comments in attached document.

Mathematics

The level and extent of the mathematics seems about right. However, relating to the Ofqual consultation, it is not clear why 40% has been chosen for the proportion of marks available for mathematics or how a mathematical mark will be defined. The SCORE analysis – *Mathematics within A-level science 2010 examinations*[1] - showed that more than 60% of question parts included some mathematics. However, it also showed that nearly all of the assessment items were low-level manipulations. It is important that the assessments address all broad areas of mathematics at a range of levels. In addition, the assessments should include multi-step mathematical problems.

Recommendation: provide clearer guidance on what constitutes a mathematical question based on analyses of recent A-level assessments

Recommendation: provide guidance on the range of levels and areas of mathematics to be assessed and the need to include multi-step problems in assessments..

[1] http://www.score-education.org/media/10033/score%20maths%20in%20science%20summary%20report.pdf

The new GCSE in mathematics will be taught for the first time in 2015. Therefore, students starting A-level physics in 2017 will arrive with a different – and, we assume, increased – level of mathematical skills. It is quite possible that here are missed opportunities within this specification because it has to accommodate the existing GCSE in mathematics and cannot build on the content in the new mathematics GCSE.

Recommendation: postpone the introduction of the new A-level in physics until 2017.

Calculus

There are some specific issues with calculus – partly to do with the structural changes at GCSE and post 16 and partly to do with the treatment of physics ideas that rely on calculus. As it stands, the mathematical content cannot include ideas about calculus – because it is not in the GCSE. The issue is not about learning how to find derivatives or integrals of functions; or learning techniques for integrating by parts. It is about the ideas of rates or change and accumulation, setting up differential equations and showing the functions that are solutions to those equations.

On the first point, it is unlikely that the new GCSE will include calculus; however, there is a requirement that all post-16 students study some mathematics. It would, therefore, be possible to ensure that all students studying physics also studied the maths that would support it – including calculus. However, this would be a major change and needs to be planned coherently – with respect to the timing, the way that ideas are presented and making the changes work with other A-levels as well.

On the second point, there are some ideas included in the criteria – such as simple harmonic motion (SHM), rate of change of momentum and exponential decay (capacitors and radioactive decay) – that can be more readily understood through a treatment based around calculus. These might be step-by-step, spreadsheet-based or graphical methods. Indeed, as it stands, it is hard to see what purpose the equations of SHM or expressions such as □p/□t perform except as equations to be learnt. There should be an approach – based on the ideas of calculus (even if it doesn't use calculus) - to introducing and deriving these equations. As it stands, the ideas are being fudged which means that many students miss out on an insight into the origin of some equations whilst those who have done Maths A-level (particularly the mechanics option) have an advantage.

Recommendation: the new A-level in physics is brought in coherently with the new post-16 mathematical requirements, including the mathematics A-level.

Recommendation: a helpful and equitable approach to calculus is adopted in the criteria, specifications and course

Appendix 3: Institute of Physics comments on proposed physics subject content

22. This appendix must be read in conjunction with sections 3-9 of this Science criteria. The AS knowledge and understanding set out in this appendix must comprise approximately 60 per cent of the AS specification, and is shown below in normal text. The A level knowledge and understanding combined must comprise approximately 60 per cent of an A level specification. Additional content required for the A level is shown in **bold.**

23. All Physics specifications must ensure that there is an appropriate balance between mathematical calculations and written explanations. They also need to ensure that practical skills are developed.

24. All Physics specifications must require knowledge and understanding of:

- the use of SI units and their prefixes;
- Newton's laws of motion;
- the estimation of physical quantities;
- the practical (?) limitations of physical measurements.

25. **Vectors and Scalars**

- the distinction between vector and scalar quantities
- resolution of vectors into two components at right angles
- addition rule for two vectors
- calculations for two perpendicular vectors.

26. **Mechanics**

- Kinematics:
    - use of kinematic equations in one dimension with constant velocity or acceleration;
    - graphical representation of accelerated motion;

Comment [A22]: Physical dimensions, consistency and dimensional analysis.

Comment [A23]: This is out of place here. It should be in the 'Mechanics' section below,.

Comment [A24]: Not clear what this means without some reference to physical examples.

Comment [A25]: As opposed to fundamental?

Comment [A26]: Is this limited to two?

Comment [A27]: A short section on statics would fit in here. And would make sense of the ideas relating to vectors and vector addition of forces.

Comment [A28]: Why specify 'accelerated' motion'? This should apply to motion generally.

- interpretation of velocity-time and displacement-time graphs.

- Dynamics:
  - use of $a=F/m$ when mass is constant;
  - one- and two-dimensional motion under constant force;
  - independent effect of perpendicular components with uniform acceleration, projectile motion.
- Energy:
  - calculation of work done by a constant force, including a force not along the line of motion;
  - calculation of exchanges between gravitational potential energy and kinetic energy;
  - principle of conservation of energy.
- Momentum:
  - definition;
  - principle of conservation of momentum;
  - calculations for one-dimensional problems.
- **Circular motion:**
  - **radian measure of angle and angular velocity (□)**
  - **application of $F = ma = mv^2/r = mr□^2$ to motion in a circle at constant speed.**
- **Oscillations:**
  - **simple harmonic motion;**
  - quantitative treatment using $a = -□^2 x$ and its

Comment [A29]: As velocity is a vector, it is impossible to draw a graph of velocity against time. The graph is of 'the magnitude of the component of velocity in a given direction against time.
If this is restricted to one-dimensional situations, it might be better to regard velocity initially as a signed quantity (one that can take either positive or negative values) rather than as a vector.

Comment [A30]: A more helpful way of expressing the relationship.

Comment [A31]: It is odd, then that $\Delta p/\Delta t$ appears in the maths appendix.

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Comment [A32]: As stated, this would include circular motion. Is that the intention? Or does constant force mean constant in direction as well as constant in size – in which case this would not include circular motion?

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Comment [A33]: Requires ability to resolve forces. Not treated in its own right so far.

Comment [A34]: Might be worth adding: 'in interactions (such as explosions and collisions).'
This section should also include impulse = force x time for which it acts; and change of momentum of an object = impulse. The link between conservation of momentum and Newton's Third Law could usefully be included specifically as a bullet point. Also, $F= \Delta p/\Delta t$ might be included. It helps make it a coherent whole.

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Comment [A35]: It is a missed opportunity not to link this with circular orbits in inverse square gravitational fields.

Comment [A36]: It is hard to do these without a context: masses on springs, small angle pendulums and so on.

Comment [A37]: This is a very sparse section and there is a missed opportunity in treating these ideas in a useful, physical-mathematical way.

Comment [A38]: It is not clear whether they are expected to understand where this comes from or they are simply expected to know the formula. If it is the latter, then that is a shame. There has to be some setting up and treatment of a differential equation.

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solution $x = A \cos \omega t$.

27. Mechanical Properties of Matter

- stress, strain, Young modulus
- force-extension graphs, energy stored

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Comment [A39]: This is another opportunity for dealing with ideas associated with calculus – accumulation (in the area under a graph). Most interesting for a non-linear F/x curve. These idea need to be developed through the physics content in a coherent way.

28. **Electric circuits**

- Current:
  - electric current as rate of flow of charge, I = Δq/Δt.
- Emf and potential difference:
  - definition of emf and concept of internal resistance;
  - potential difference in terms of work done per unit charge.
- Resistance:
  - Definition: R = V/I
  - resistivity;
  - Ohm's law.
- Circuits:
  - conservation of charge and energy in circuits;
  - relationships between currents, voltages and resistances in series and parallel circuits;
  - power dissipated;
  - potential divider circuits.
- **Capacitance:**
  - **definition;**
  - **energy of a capacitor;**
  - **quantitative treatment of charge and discharge curves.**

Comment [A40]: Once again, this is a fudge. What is expected from the deltas? If it is rate of change, then it should be addressed properly. If it ends up as Q/t, then there is no need to introduce deltas.

Comment [A41]: Why is one a concept and the other a definition? Also, they are quite distinct ideas – that happen to be brought together in the treatment of a cell as a practical source of voltage. If it is supposed to be about the cell (V=E-Ir), then it should state that. And EMF should be defined elsewhere.

Deleted: energy transfer

Comment [A42]: I assume this is the definition meant.

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Comment [A43]: If R is defined as V/I, what is Ohm's Law and what are we to say about its status (is it a logical consequence of the definition, or an empirical result?)

Comment [A44]: Is this intended to include Kirchoff's laws. If so, that needs to be clarified. These ideas certainly lead to Kirchoff's laws.

Comment [A45]: Loose wording. Is energy conserved 'in a circuit'?

Comment [A46]: We have now had three terms: emf, potential difference, and voltage – without any indication of what each is to be taken to mean, or why all three are needed.

Comment [A47]: Very general, and rather vague. Would it be clearer simply to say Kirchhoff's First and Second Laws?

Comment [A48]: By what? In what?

Comment [A49]: This has to be treated as a derivation and understanding. It would be a shame if it simply a formula that is learnt and applied without knowing where it comes from.

Comment [A50]: Series and parallel. Relates to electric fields later so it is worth doing.

Comment [A51]: Again, there needs to be an approach to this (using ideas from calculus) that help students understand the physical processes. Step-by-step graphical techniques are useful here. But they have to explicit if they are to be assessed (and therefore certain to be studied).

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29. **Waves**

- qualitative treatment of polarisation and diffraction;
- path difference, phase and coherence, interference;
- graphical treatment of superposition and stationary waves.

30. **Matter**

- **Molecular kinetic theory:** [CI]

  ideal gases; $pV = NkT$;

  - **absolute zero;**
  - **relationship between temperature and average molecular kinetic energy;**
  - **energy of an ideal gas.**

- **Internal energy:**
  - **idea of internal energy;**
  - **energy required for temperature change = mcΔθ.**

31. Quantum and **nuclear physics**

- Photons and particles:
  - photon model to explain observable phenomena;
  - evidence supporting the photon model;
  - wave-particle duality, particle diffraction.
- **Nuclear decay:**
  - **connections between nature, penetration and range of ionising particles;**
  - **evidence for existence of nucleus;**
  - **activity of radioactive sources and idea of half-life;**
  - **modelling with constant decay probability leading to exponential decay;**
  - **nuclear changes in decay.**
- **Nuclear energy:**

Comment [A52]: This assumes gas laws. As does the mathematics appendix. If gas laws are included, then worth making them explicit.

Comment [A53]: This phrase doesn't really have any meaning. There needs to be some clarity about what is to be studied. There is an opportunity for some ideas about temperature changes, heating and working to be covered here.

Comment [A54]: Such as? Some examples would be useful.

Comment [A55]: This is the first mention of diffraction. It needs to be covered in the section on waves.

Comment [A56]: Are gammas being called 'particles' here? Better to say 'of emissions from radioactive substances'.

Comment [A57]: Not clear what is meant by modeling in this context. However, the ideas that might be used (step-by-step iterative models) need to be introduced in other contexts as well (capacitors, SHM and so on) to develop a coherent approach to these problems that require some way of solving differential equation problems.

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= fission and fusion processes;

- ***E* = *mc*^{2} applied to nuclear processes;**

- **calculations relating mass difference to energy change.** 32.

Fields

- **Force fields:**
  - **concept and definition;**
  - **gravitational force and field for point (or spherical) masses;**
  - **electric force and field for point (or spherical) charges in a vacuum;**
  - **electric and gravitational potential and changes in potential energy;**
  - **uniform electric field;**
  - **similarities and differences between electric and gravitational fields.**
- **B-fields:**
  - **force on a straight wire and force on a moving charge in a uniform field.**
- **Flux and electromagnetic induction:**
  - **concept and definition;**
  - **Faraday's and Lenz's laws;**
  - **emf equals rate of change of magnetic flux linkage.**

Comment [A58]: Assume this means inverse square fields. In which case, this should be made explicit.

Comment [A59]: And uniform fields should come before radial fields.

Comment [A60]: Relate to capacitors. Good reason to do capacitors in series and parallel because the ideas can be unified with the C=Aε/d.

Comment [A61]: Deflection of charges in Teltron tubes. Relates to accelerators etc.

Comment [A62]: Is this going to lead on to inductance?

Appendix 3

C. Physics

	Mathematical skills	Exemplification of mathematical skill in the context of A level Physics (assessment is not limited to the examples given below)
C.0	**Arithmetic and numerical computation**	
C.0.1	Recognise and make use of appropriate units in calculations.	Candidates may be tested on their ability to: • identify the correct units for physical properties such as $m\ s^{-1}$, the unit for velocity. • Convert between units with different prefixes e.g. cm^3 to m^3.
C.0.2	Recognise and use expressions in decimal and standard form.	Candidates may be tested on their ability to: • use physical constants expressed in standard form such as $c = 3.00 \times 10^8\ m\ s^{-1}$.
C.0.3	Use ratios, fractions and percentages.	Candidates may be tested on their ability to: • calculate efficiency of devices • calculate percentage uncertainties in measurements.
C.0.4	Make estimates of the results of calculations (without using a calculator).	Candidates may be tested on their ability to: • estimate the effect of changing experimental parameters on measurable values.
C.0.5	Use calculators to find and use power, **exponential and logarithmic functions.**	Candidates may be tested on their ability to: • **solve for unknowns in decay problems such as** $N = N_o e^{-at}$.
C.0.6	Use calculators to handle sin ***x,*** cos ***x,*** tan ***x*** when ***x*** is expressed in degrees or radians.	Candidates may be tested on their ability to: • calculate the direction of resultant vectors

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C.1	Handling data	
C.1.1	Use an appropriate number of significant figures.	Candidates may be tested on their ability to: • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement
C.1.2	Find arithmetic means.	Candidates may be tested on their ability to: • calculate a mean value for repeated experimental readings.
C.1.3	Understand simple probability.	Candidates may be tested on their ability to: • Understand probability in the context of radioactive decay.
C.1.4	Make order of magnitude calculations.	Candidates may be tested on their ability to: • evaluate equations with variables expressed in different orders of magnitude.
C.1.5	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers	Candidates may be tested on their ability to: • determine the uncertainty where two readings for length need to be added together

Comment [A63]: This is not what 'making an order of magnitude calculation' means.

C.2	**Algebra**	
C.2.1	Understand and use the symbols: =, <, <<, >>, >, oc, -1, A	Candidates may be tested on their ability to: • recognise the significance of the symbols in the expression F oc Ap/At
C.2.2	Change the subject of an equation, including non-linear equations.	Candidates may be tested on their ability to: • rearrange E = mc2 to make m the subject.
C.2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities.	• Candidates may be tested on their ability to: • calculate the momentum p of an object by substituting the values for mass m and velocity v into the equation p = my.
C.2.4	Solve algebraic equations, including quadratic equations.	Candidates may be tested on their ability to: solve kinematic equations for constant acceleration such as v = u + at and s = ut + 1/2 at2
C.2.5	**Use logarithms in relation to quantities that range over several orders of magnitude.**	Candidates may be tested on their ability to: • **recognise and interpret real world examples of logarithmic scales.**
C.3	**Graphs**	
C.3.1	Translate information between graphical, numerical and algebraic forms.	Candidates may be tested on their ability to: • say in words what a given graph means, or sketch the form of a graph from a description in words, or from an algebraic equation.

Comment [A64]: Force is more than proportional to dp/dt it is equal to it.

Comment [A65]: Rearranging E = $^1/_2$ mv^2 to make v the subject would be a better example.

Comment [A66]: How is this different from C2.2?

Comment [A67]: Do we really want to require this? Where is it needed in A-level physics? In the example you give (s = ut + …), why would you ever want to solve for t?

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Comment [A68]: This would be a clearer statement.

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C.3.2	Plot a graph showing how one variable varies with another, using experimental or other data.	Candidates may be tested on their ability to: • plot graphs of extension of a wire against force applied.
C.3.3	Understand that y = *mx* + c represents a linear relationship.	Candidates may be tested on their ability to: • rearrange and compare v = *u* + *at* with y = *mx* + c for velocity-time graph in constant acceleration problems.

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Comment [A69]: Does this really mean 'using data you have collected or been given'?

C.3.4	Determine the slope and intercept of a linear graph.	Candidates may be tested on their ability to: • Read off and interpret intercept point from a graph e.g. the initial velocity in a velocity-time graph.
C.3.5	Calculate rate of change from a graph showing a linear relationship.	Candidates may be tested on their ability to: • Calculate acceleration from a linear velocity-time graph.
C.3.6	Draw and use the slope of a tangent to a curve as a measure of rate of change.	Candidates may be tested on their ability to: • draw a tangent to the curve of a displacement—time graph and use the gradient to approximate the velocity at a specific time.
C.3.7	Distinguish between instantaneous rate of change and average rate of change	Candidates may be tested on their ability to: • understand that the gradient of the tangent of a displacement—time graph gives the velocity at a point in time which is a different measure to the average velocity.
C.3.8	Understand the possible physical significance of the area between a curve and the *x* axis and be able to calculate it or estimate it by graphical methods as appropriate.	Candidates may be tested on their ability to: • recognise that for a capacitor the area under a voltage-charge graph is equivalent to the energy stored.
C.3.9	Solve equations involving rates of change, e.g. Lx /At = —*Ax* using a graphical method or spreadsheet modelling	Candidates may be tested on their ability to: • determine g from distance-time plot, projectile motion • **determine details of simple harmonic motion from defining equation**
C.3.10	**Interpret logarithmic plots**	Candidates may be tested on their ability to: • **Obtain time constant for capacitor discharge by interpreting plot of log *V* against time.**

Comment [A70]: As velocity is a vector, a velocity-time graph is an impossibility.

Comment [A71]: For the same reason, it is not possible, in general, to draw a 'displacement-time graph'. Like so-called velocity-time graphs, these are only useful for situations of motion in 1D

Comment [A72]: What is a 'logarithmic plot'?

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C.3.11	**Use logarithmic plots to test exponential and power law variations.**	Candidates may be tested on their ability to: • **Use logarithmic plots with decay law of radioactivity / charging and discharging of a capacitor.**

C.3.12	Sketch relationships which are modelled by $y = k/x$, **$y = 10(^2$, $y = kb?$,** $y = \sin x$, $y = \cos x$, **$y = e^{lk}$, and $y = \sin^2 x$, $y = \cos^2 x$ as applied to physical relationships**	Candidates may be tested on their ability **to:** **Sketch relationships between pressure and volume for an ideal gas.**
C.4	**Geometry and trigonometry**	
C.4.1	Appreciate angles in regular 2D and 3D structures.	Candidates may be tested on their ability to: • interpret force diagrams to solve problems.
C.4.2	Visualise and represent 2D and 3D forms including two- dimensional representations of 3D objects.	Candidates may be tested on their ability to: • draw force diagrams to solve mechanics problems.
C.4.3	Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres.	Candidates may be tested on their ability to: • calculate the area of the cross section to work out the resistance of a conductor given its length and resistivity.
C.4.4	Use Pythagoras' theorem, and the angle sum of a triangle.	Candidates may be tested on their ability to: • calculate the magnitude of a resultant vector.
C.4.5	Use sin, cos and tan in physical problems.	Candidates may be tested on their ability to: • resolve forces into components.
C.4.6	Use of small angle approximations including sin $6 \cdot 6$, tan $6 \cdot 6$, cos 6 1 for small 6 where appropriate	Candidates may be tested on their ability to: • Calculate fringe separations in interference patterns.
C.4.7	Understand the relationship between degrees and radians and translate from one to the other.	Candidates may be tested on their ability to: • Convert angle in degrees to angle in radians.

Comment [A73]: So gas laws need to be included explicitly.

Comment [A74]: Not in criteria above.

Comment [A75]: Is this in the criteria above?

Comment [A76]: See next comment.

Deleted: , resolving forces into components to solve problems

Comment [A77]: This repeats the last part of the entry for C4.4 above. It actually fits better here.

Comment [A78]: This is not in the current criteria above.

Appendix 4: Society of Biology overview and comments on proposed biology subject content

The Society of Biology considers the main issues with the current A-level to lie more with assessment (including assessment of practical work) than with the biology content. Concerns from bioscience higher education regarding the inadequate preparation of A-level students have focused more on capabilities and skills than on knowledge, although students' ability to integrate and apply knowledge does remain an issue. That said, there are issues with the proposed content that must be resolved.

The potential range of topics in biology, plus and a long tradition of weak integration with mathematics, means that the task of improving A levels in this subject presents different challenges to those of the other sciences. Given these issues, the limited timeframe for this consultation and the planned work of the Society's Curriculum Committee (to be published in September 2014), we have not commented on the detail of the content. Instead, this appendix sets out a number of over-arching issues that need to be addressed in the proposed criteria. It is essential that the biology drafters work closely with the bioscience community to resolve these.

The comments below draw on responses from a cross-section of the Society's member organisations and individual members, including teachers, academics, education researchers and other relevant stakeholders.

1. **Some major changes are needed to the biology content**
1. ***Statements should be clearly structured under the Big Ideas in biology***

The ability to understand and make synoptic connections between the molecular, cellular, whole organism and ecosystem level is a fundamental skill in biology; as is the ability to apply core biological concepts across a range of different organisms. However, these are skills that many students entering higher education currently lack. The A-level reform is an ideal opportunity to address this, but there is no evidence that the proposed criteria will ensure these much needed improvements.

Whilst the proposed criteria are loosely structured around the hierarchical levels in biology, they would benefit from making these levels more explicit. In addition, these issues could be helpfully addressed by introducing the big ideas in biology to the A-level criteria (in a similar manner to that used for the draft reformed GCSE criteria), and/or by adding an introductory narrative to each of the sections. These changes would also serve to highlight the key concepts that students should have gained on completion of an A-level in biology.

The current (September 2011) version of the biology criteria contains the introductory statement: 'Living organisms, including plants, animals and micro-organisms, interact with each other and with the non-living world. The living world can be studied at population, organism, cell and molecular levels. There are fundamental similarities as well as differences between plants, animals and micro-organisms'. The removal of this statement from the new draft criteria represents a step backwards in attempts to ensure biology A-level challenges students to genuinely understand and integrate their knowledge across the subject. A version of this statement should be re-introduced.

2. ***Some statements are misleading and may support misconceptions***

The criteria statements should give clear guidance to awarding organisations on constructing specifications which aid understanding rather than reinforce misconceptions. However, some of the draft statements are at risk of giving a misleading or narrow understanding of the concepts they represent. Examples include:

- The sequence of bases in the DNA molecule determines the structure of proteins, including enzymes. [AS-/A-level]
- **Transfer of genetic information from one generation to the next can ensure continuity of species or lead to variation within a species and eventual formation of new species. [A-level only]**

The development of the reformed GCSE criteria has involved significant input from the science community, including the professional bodies for the three sciences, to ensure that terminology is used appropriately to support student understanding and improve consistency across the sciences. The use of the word 'energy' is a prime example. This process has not yet been applied to the A-level criteria, where outdated references to energy remain, leading to an inconsistency in the use of term at GCSE and A-level. For example:

- **Energy flows through ecosystems and the efficiency of transfer through different trophic levels can be measured. [A-level]**
- describe the differences between the trophic levels of organisms within an ecosystem [GCSE]
- describe pyramids of biomass and explain, with examples, how biomass is lost between the different trophic levels [GCSE]
- **calculate the efficiency of biomass transfers between trophic levels and explain how this affects the number of organisms at each trophic level [GCSE – single award]**

3. *The statements are inconsistent in nature*

The statements in the biology A and AS-level criteria vary greatly in the extent to which they are open to interpretation. Some are very precise (for example, 'In cellular respiration, glycolysis takes place in the cytoplasm and the remaining steps in the mitochondria'); others are more broad or high level (for example, 'In living organisms nucleic acids (DNA and RNA), carbohydrates, proteins, lipids, inorganic ions and water all have important roles and functions related to their properties').

Recommendations:

- The biology drafters should work closely with the bioscience community to:
  - consider how the content statements might be more explicitly formatted around the structural levels in biology – from molecular, to cellular, to whole organism, to ecosystem;
  - develop statements to reflect the big ideas in biology that all students should understand by the end of their course, and to devise the narrative to accompany each sub-section;
  - develop and re-introduce a version of the introductory statement referenced above, so that the new criteria ensure that general biological concepts are taught, learned and assessed across animals, plants and micro-organisms;
  - ensure that the statements support student understanding, rather than give misleading impressions of any concepts;
  - ensure that terminology is used consistently between the GCSE and A-level content and that it supports a clear understanding of the concepts covered;
  - consider whether more consistency in the nature of the statements would be beneficial, and to ensure that statements are sufficiently precise to enable the development of high quality, appropriate specifications that reflect accurate and contemporary biology.

Comment [GG79]: Although this is correct, it gives a very narrow overview of the concept as only <2% of the [human] genome is protein-coding. This would benefit from being redrafted into a broader statement along the lines of 'The sequence of bases in an organism's DNA (its genome) encode instructions to help an organism grow, develop and function. Often, these instructions are for other molecules, such as proteins, including enzymes.' Although more lengthy, this gives a more accurate description and could be refined with more time.

Comment [GG80]: The phrasing of this statement is misleading. '…can ensure *or* lead to…' The two aren't always mutually exclusive, for example, the latter *always* takes place (at a genetic level) in sexual species, even if the evolution of a new species relies on other factors too.

Comment [GG81]: Energy is not a tangible substance that can 'flow'. Therefore this term is misleading.

Comment [GG82]: Biomass transfer can be more readily evidenced and calculated than 'energy' transfer

2. Coherence with GCSE criteria is essential

Comparisons of the GCSE and AS/A-level criteria are made somewhat challenging due to the prescriptive nature of the GCSE statements (which specify 100% of the content) compared with the AS-/A-level statements (which specify only 60% of the core content). In spite of this, it is still apparent that the lack of coherence between the processes of GCSE and A-level reforms has led to a number of issues that need to be rectified. In terms of the biology A/AS-level criteria these include:

1. Some statements fail to raise demand beyond that of the new biology (or double award science) GCSEs

New GCSEs in the sciences have been developed to raise the standard and demand of these qualifications. However, the A-level content has not changed to reflect this. Consequently, some of the statements in the proposed AS- and A-level criteria now cover almost identical content to statements in that of the reformed GCSEs, leading to risk of repetition. This is particularly an issue where it is not clear that the A level statement requires a more in-depth understanding of the concept now presented at GCSE. For example:

- originally classification systems were based on observable features but more recent approaches draw on a wider range of evidence to clarify relationships between organisms [AS-/A-level].
- explain the impact of developments in evolutionary biology on classification systems, including the three domain model based on DNA analysis and the phenotype model of kingdom, phylum, class, order, family, genus and species [GCSE]

- substances are exchanged by passive or active transport across exchange surfaces [AS-/A-level]
- describe and explain how substances are transported into and out of cells through diffusion, osmosis and active transport [GCSE]

- In complex multicellular organisms cells are organised into tissues, tissues into organs and organs into systems. [AS-/A-level]
- the fundamental units of living organisms are cells, which may be part of highly adapted structures such as tissues, organs and organ systems enabling living processes to be performed effectively [a 'big idea' statement at GCSE]

2. Statements need to better reflect a contemporary understanding of biology

The draft reformed GCSE criteria now contain statements that require a more modern understanding of some aspects of biology than implied by the A-level criteria. In addition, some of these GCSE statements appear to require a deeper understanding of the concepts than similar topics at A-level. For example:

- **Sequencing projects have read the genomes of organisms ranging from microbes and plants to humans. This allows the sequences of the proteins that derive from the genetic code to be predicted. [A-level]**
- discuss the potential importance for medicine of our increasing understanding of the human genome [GCSE]

- The sequence of bases in the DNA molecule determines the structure of proteins, including enzymes. [AS-/A-level]
- **The genome is regulated by a number of factors [A-level]**
- describe simply how the genome, and its interaction with the environment, influences the development of the phenotype of an organism [GCSE]

Comment [GG83]: This is a new statement and would benefit from more work to ensure clarity and progression from GCSE

Recommendations:

- The biology drafters should work closely with the bioscience community to:
  - redevelop these statements in the AS-/A-level criteria to ensure that the progression required is more apparent;
  - ensure that the statements in the AS-/A-level criteria reflect a more modern understanding of the concepts covered.

3. Other issues identified with the biology content

a) More consideration must be given to the AS-/A-level split and core content

More consideration needs to be given to the way in which content has been divided between the AS and A-level, given the re-defined relationship between the two qualifications (following their de-coupling as part of the reform). Commenting on this in detail is challenging in the timescale of the consultation, and is further complicated by the fact that the purpose of the AS-level qualification is also currently under consultation.

Given the breadth of biology, more consultation is also required to ensure that the topics included in the core content are the most appropriate, and that no crucial areas of content are absent from the proposed criteria. For example, should there be an increased focused on health and disease? Given that it is likely that some concepts will now be introduced earlier, or in more detail, in the reformed GCSEs, there may also be scope to introduce additional content at AS-/A-level (or build towards a deeper understanding of the concepts introduced at GCSE).

b) Unbalancing of sections due to re-ordering

Whilst we recognise that the criteria do not represent an order for teaching or specification content, the re-ordering of content in the new criteria (following removal of 'cellular control' from existing criteria) has unbalanced some of the sections and made others less coherent. For example, 'biological molecules' is now very enzyme focused, with little mention of other (non-protein) biological molecules. This risks giving a limiting impression of the different main types of biological molecules (including carbohydrates, lipids and nucleic acids) and the range within them. The statement 'the genome is regulated by a number of factors' does not sit coherently with other statements in the 'control systems' section.

Recommendations:

- The biology drafters should work closely with the bioscience community to:
  - ensure that content is split appropriately between the AS- and full A-level qualification, in order to better meet the intended purposes (once clarified and confirmed) of the two qualifications;
  - provide confidence that the core content covers the topics considered to be essential to progression in the subject;
  - ensure that the arrangement of content does not give a limiting impression of the subject.

4. Insufficient detail regarding the practical skills required in A level Biology

The proportion of the criteria devoted to knowledge and understanding, and to the mathematical requirements, is significantly greater than that for the practical skills (in the 'Working Scientifically' appendix), and these skills are shared across the sciences. Given strong concerns from bioscience higher education regarding the students' lack of practical skills, this is a significant oversight. More work needs to be done to define the range and depth of biology practical skills needed by universities; this will be one of the priority areas for the Society's Curriculum Committee. However skills such as: making serial dilutions, advanced microscopy, random sampling in the field, and measuring the effects of biochemical reactions are all significant omissions in the draft criteria.

Although assessment is outside the scope of this consultation, the content of A-level Biology cannot be considered separate from its assessment. Given the importance of fieldwork to biology it is illogical that skills in this area are proposed to be assessed entirely differently in geography compared to biology.

Recommendations:

- The biology drafters should work closely with the bioscience community to define and add the practical skills requirements for AS- and A-level biology.

5. Mathematical requirements

The Society welcomes an increased emphasis on the quantitative skills needed to prepare students for further progression in biology. If properly implemented (for example, by ensuring that the mathematical requirements are embedded in biological contexts in both the teaching and assessment of the subject), this should help to address the mathematical skills gap currently faced by biology students entering bioscience higher education[2]. However, the Society has a number of concerns regarding the mathematical requirements as they are currently laid out and, potentially, the weighting assigned to the assessment of mathematical skills.

1. Absence of some key skills from the requirements

Some key mathematical skills for biology are currently absent from the requirements – for example, skills related to dealing with the uncertainty of large data sets (including the ability to select appropriate statistical analyses[3]), understanding standard deviation, carrying out serial dilutions, and so on. Furthermore, some of these skills do appear in the mathematical requirements for the other science subjects, and it is not clear what rationale has been used to include requirements relevant to several of the sciences in some of the subjects but not others. For example:

- 'identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined' [from physics]
- 'understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or estimate it by graphical methods as appropriate' [from physics]
- 'understand the differences between qualitative and quantitative data' [from psychology]
- 'understand the difference between primary and secondary data' [from psychology]
- 'recognise skewed distributions' [from psychology]
- 'know the characteristics of a normal distribution' [from psychology]
- **'choose an appropriate statistical test' [from psychology]**
- **'use statistical tables to determine significance' [from psychology]**

In addition, the use of computer modelling, drawing from large databases, is now a significant part of contemporary biology. Computational skills should also be considered as a potential part of a modern A-level Biology qualification.

2. Key requirements are also absent from AS-level

The rationale for the AS/A-level only split for the mathematical requirements is unclear. Most of the skills that are A-level only should appear at AS-level as well. For example:

- 'use a statistical test'

[2] A survey of the mathematics landscape within bioscience undergraduate and postgraduate higher education in the UK, Dr Jenny Koenig, 2011
[3] A world full of data: statistics opportunities across A level sciences, Roger Porkess, 2013

- 'determine the intercept of a graph'
- 'use calculators to find and use power' [appears in AS-level in chemistry and physics, but is currently A-level only in biology]

3. ***Some exemplifications are insufficiently applied, engaging or challenging***

Some of the biology exemplifications seem less challenging, relevant, applied or interesting compared with the other science subjects. For example:

- 'use ratios, fractions and percentages' appears in both biology and physics, but the physics exemplifications include 'calculate percentage uncertainties in measurements' – this is also applicable to biology but not included.

This risks reinforcing the incorrect perception that biology is a soft subject compared with the other core sciences.

4. ***Not all requirements are assessable via a written exam***

Whilst they are valuable skills that need to be developed, not all of the mathematical requirements proposed can be readily assessed in a written exam context. For example:

- 'make estimates of the results of calculations'

This can only be assessed if students don't take a calculator into the exam, which would then preclude the assessment of other requirements. However, these skills could be demonstrated through the assessment of practical activities, which could include the handling of real data to allow the analysis of larger, messier data than is currently used in schools.

Recommendations:

- The biology drafters should work closely with the bioscience community to:
  - re-write the mathematical requirements to ensure that they are fully representative of the subject and adequately prepare students for bioscience higher education;
  - consider developing requirements that outline the computational skills required of students at this level.
- Consideration should be given to whether and how some of the mathematical requirements might be appropriately assessed as part of the assessment of practical work.
- Appropriate continuing professional development support (CPD) must be made available to help teachers embed the maths skills into biological contexts (rather than teaching the maths separately to the biology). Maths skills form part of the 'big biology story' and therefore need to link to content as well as other skills, such as practical skills. Especially since practical activities provide unique and valuable opportunities to contextualise, apply and assess the mathematical requirements

6. **Weighting of mathematical skills within biology**

Whilst not directly related to this consultation, there is an issue regarding the weighting assigned to the mathematical requirements within the biology assessment. It is not currently clear on what evidence or rationale the selection of a 10% weighting for biology is based. Professor Mark Smith's report[4] quoted evidence from the 2012 SCORE research[5] that the

[4] Independent Chair's report on the review of current GCE 'specification content' with subject criteria, Professor Mark Smith, July 2013

[5] Mathematics within A-level science 2010 examinations, SCORE, April 2012

amount of mathematical content (at levels 1 and 2) assessed in a complete biology A-level ranged from 13-24% across the different awarding organisations in the 2010 examinations. The similar figures for chemistry and physics were 24-43% and 47-57% respectively.

The weightings selected for chemistry (20%) and physics (40%) in the new A-level proposals fall within the range outlined in the report. Therefore, it is not clear why biology is given a weighting below this range. However, without access to the evidence or rationale on which this decision is based, it is difficult to comment on whether this is an adequate weighting to address the significant concerns regarding students' lack of quantitative skills on entry to bioscience higher education.

In addition, the list of mathematical requirements for biology is at least as long as those for chemistry and physics (which we are pleased to see). It is therefore unclear whether it is realistic to cover all the requirements in only 10% of the marks (especially without further information on the timescale in which the full list of requirements must be covered).

Recommendation:

- The evidence and rationale on which the mathematical skills weightings are based should be made available for scrutiny and comment by the bioscience community. This will allow for more meaningful discussions to be had regarding whether 10% is a sufficient weighting for biology.

Appendix 5: Royal Society of Chemistry statement on proposed content and consultation

The Royal Society of Chemistry considers the main issues with the current A-level to be more about assessment (including assessment of practical work) than the specific chemistry content.

The content proposed for the new chemistry AS and A-level qualifications is almost the same as the current criteria and it covers the topics we would expect to see in these qualifications.

Specific comments about the chemistry content:

Section 24

- Common usage is now formulas rather than formulae

Section 25

- *Z* should be italicised as it is a variable

Section 28

- In the equation $Rate = k[A]^m[B]^n$ m,n are superscripts

Section 29. Equilibria

- In K_c, K_w and K_a c,w and a should all be subscripts
- The end of the first bullet point currently reads; '…Equilibrium constants, *Kc.* **Calculation of *Kc* and reacting quantities**'. It seems odd to introduce equilibrium constants, *Kc* at AS but only use them in calculations at A-level.

Recommendation:

- Equilibrium constants, *Kc* should be an A-level rather than an AS topic. So the statement is changed to; '…**Equilibrium constants, *Kc.* Calculation of *Kc* and reacting quantities**'

Sections 25, 30 and 31

- s, p, d should not be italicised as they are labels not variables

Section 32

- Given that hydrolysis is a key reaction in biology, further consideration should be given as to whether it should sit within AS rather than A Level

Appendix 6: Mathematical requirements and exemplifications

B.0.3

- The example given for 'Making estimates of the results of calculations (without using a calculator)' would not be possible to do without a calculator as it is a logarithm.

Recommendation:

- Estimation questions as far as we're aware would be new to A-level chemistry. We are not against including this, but a better example is required.