

A Proposal to Integrate Physics Units 1 and 2 with Physics Units 3 and 4.

Introduction

This proposal has been prepared for consideration by those teachers who have been required to teach a composite class comprising Units 1/2 students and Units 3/4 students.

Unfortunately, it is not uncommon for teachers in this position to have little or no allowance made to their teaching load. Consequently, any Units 1/2 content that does not have direct implications for Units 3/4 has been omitted.

It is proposed that students be given no agency over curriculum choices through the Unit 2 Area of Study 2 Options: *How does physics inform contemporary issues and applications in society?* Student agency would be limited to choice of inquiry from the limited set of topics offered in Unit 4 Area of Study 2, viz. motion, fields or light, the last of these being an unlikely topic with respect to the relative paucity of content suitable for such an investigation.

This proposal means that students undertaking this highly limited course will miss out on becoming well-informed citizens with respect to thermal and nuclear physics, with implications for understanding important societal issues such as climate change and energy choices respectively. Preparing students to go on to trades in the electrical field has also been truncated by the need to reduce circuit electricity and related uses, including household electrical safety.

Finally, it is envisaged that this course would be taught each year to composite classes.

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Unit 3: How do fields explain motion and electricity

Area of Study 1: How do physicists explain motion in two dimensions? (U3AoS1)

Concepts used to model motion (U2AoS1)

- identify parameters of motion as vectors or scalars (U2AoS1)
- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: (U2AoS1)
$$v = u + at, v^2 = u^2 + 2as, s = \frac{1}{2}(u + v)t, s = ut + \frac{1}{2}at^2, s = vt - \frac{1}{2}at^2$$
 (U2AoS1)
- analyse, graphically, non-uniform motion in a straight line (U2AoS1)

Newton's laws of motion. (U3AoS1)

- investigate and apply theoretically and practically Newton's three laws of motion in situations where two or more coplanar forces act along a straight line and in two dimensions. (U3AoS1)
- model forces as vectors acting at the point of application (with magnitude and direction), labelling these forces using the convention 'force on A by B' or $F_{\text{on A by B}} = -F_{\text{on B by A}}$ (U2AoS1)
- apply Newton's three laws of motion to a body on which forces act: $a = \frac{F_{\text{net}}}{m}$, $F_{\text{on A by B}} = -F_{\text{on B by A}}$ (U2AoS1)
- explain changes in momentum as being caused by a net force: $\Delta p = F_{\text{net}}\Delta t$ (U2AoS1)
- apply concepts of momentum to linear motion: $p = mv$ (U2AoS1)
- investigate and analyse theoretically and practically impulse in an isolated system for collisions between objects moving in a straight line: $F\Delta t = m\Delta v$. (U3AoS1)
- apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces (U2AoS1)
- model the force due to gravity, F_g , as the force of gravity acting at the centre of mass of a body, $F_{\text{on body by Earth}} = mg$, where g is the gravitational field strength (9.8 N kg^{-1} near the surface of Earth) (U2AoS1)
- investigate and analyse theoretically and practically the motion of projectiles near Earth's surface, including a qualitative description of the effects of air resistance. (U3AoS1)
- investigate and analyse theoretically and practically the uniform circular motion of an object moving in a horizontal plane: $\left(F_{\text{net}} = \frac{mv^2}{r}\right)$, including:. (U3AoS1)
 - a vehicle moving around a circular road. (U3AoS1)
 - a vehicle moving around a banked track. (U3AoS1)
 - an object on the end of a string. (U3AoS1)
- model natural and artificial satellite motion as uniform circular motion. (U3AoS1)
- investigate and apply theoretically Newton's second law to circular motion in a vertical plane (forces at the highest and lowest positions only). (U3AoS1)

Relationships between force, energy and mass.¹ (U3AoS1)

- investigate and apply theoretically and practically the concept of work done by a force using: (U3AoS1)
 - work done = force $\times$ displacement. (U3AoS1); $W = F \cos \theta$, where force is constant (U2AoS1)
 - work done = area under force vs distance graph (one dimensional only). (U3AoS1)
 - analyse transformations of energy between kinetic energy, elastic potential energy, gravitational potential energy and energy dissipated to the environment (considered as a combination of heat, sound and deformation of material):. (U3AoS1);
 - investigate and apply theoretically and practically the laws of energy and momentum conservation in isolated systems in one dimension
 - analyse rate of energy transfer using power: $P = \frac{E}{t}$ (U2AoS1)
 - kinetic energy at low speeds: $E_k = \frac{1}{2}mv^2$; elastic and inelastic collisions with reference to conservation of kinetic energy. (U3AoS1)
 - elastic potential energy: area under force-distance graph including ideal springs obeying Hooke's Law: $E_s = \frac{1}{2}kx^2$. (U3AoS1)
- investigate and analyse theoretically and practically Hooke's Law for an ideal spring: $F = -kx$, where x is extension (U2AoS1)²
- analyse and model mechanical energy transfers and transformations using energy conservation: (U2AoS1)
 - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$ (U2AoS1)
 - elastic potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$ (U2AoS1)
 - kinetic energy: $E_k = \frac{1}{2}mv^2$ (U2AoS1)

Area of Study 2: How do things move without contact? (U3AoS2)

Fields and interactions. (U3AoS2)

- describe gravitation, magnetism and electricity using a field model. (U3AoS2)
- investigate and compare theoretically and practically gravitational, magnetic and electric fields, including directions and shapes of fields, attractive and repulsive effects, and the existence of dipoles and monopoles. (U3AoS2)
- investigate and compare theoretically and practically gravitational fields and electrical fields about a point mass or charge (positive or negative) with reference to: (U3AoS2)
 - the direction of the field. (U3AoS2)
 - the shape of the field. (U3AoS2)
 - the use of the inverse square law to determine the magnitude of the field. (U3AoS2)

¹ Momentum is not kinetic energy, yet the Study Design conflates them. The attempt here has been to separate them into different places. This can only be partially successful, since they are complementary analytic tools for the same set of phenomena.

² Springs can be used as an analogue of fields. Energy stored in a spring is analogous to potential energy stored in a field; potential energy returned from the spring is analogous to potential energy returned from the field as useful energy, such as kinetic energy. This is why it is suggested here that Hooke's Law etc. be set at the end of this unit as a pre-cursor to the field concept in Unit 3 Area of Study 2.

- potential energy changes (qualitative) associated with a point mass or charge moving in the field. (U3AoS2)
- investigate and apply theoretically and practically a field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops and solenoids. (U3AoS2)
- identify fields as static or changing, and as uniform or non-uniform. (U3AoS2)

Effects of fields. (U3AoS2)

- analyse the use of an electric field³ to accelerate a charge, including:. (U3AoS2)
 - electric field and electric force concepts: $E = k \frac{Q}{r^2}$ and $F = k \frac{q_1 q_2}{r^2}$. (U3AoS2)
 - potential energy changes in a uniform electric field: $W = qV$, $E = \frac{V}{d}$. (U3AoS2)
 - the magnitude of the force on a charged particle due to a uniform electric field: $F = qE$. (U3AoS2)
- analyse the use of a magnetic field to change the path of a charged particle, including:. (U3AoS2)
 - the magnitude and direction of the force applied to an electron beam by a magnetic field: $F = qvB$, in cases where the directions of v and B are perpendicular or parallel. (U3AoS2)
 - the radius of the path followed by an electron in a magnetic field: $qvB = \frac{mv^2}{r}$, where $v \ll c$. (U3AoS2)
- analyse the use of gravitational fields to accelerate mass, including:. (U3AoS2)
 - gravitational field and gravitational force concepts: $g = G \frac{M}{r^2}$ and $F_g = G \frac{m_1 m_2}{r^2}$. (U3AoS2)
 - potential energy changes in a uniform gravitational field: $E_g = mg\Delta h$. (U3AoS2)
- analyse the change in gravitational potential energy from area under a force vs distance graph and area under a field vs distance graph multiplied by mass. (U3AoS2)

Application of field concepts. (U3AoS2)

- apply the concepts of force due to gravity and normal force including in relation to satellites in orbit where the orbits are assumed to be uniform and circular. (U3AoS2)
- model satellite motion (artificial, Moon, planet) as uniform circular orbital motion: $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$. (U3AoS2)
- describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel, whereas masses only attract each other. (U3AoS2)
- investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, $F = nIlB$, where the directions of I and B are either perpendicular or parallel to each other. (U3AoS2)
- investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about

³ It is unfortunate and confusing that the electric field vector and the symbol for energy are indistinguishable, so it is important to get students to take note of and appreciate the context in which the symbol is being used.)

an axis in a uniform magnetic field and including the use of a split ring commutator. (U3AoS2)

- investigate, qualitatively, the effect of current, external magnetic field and the number of loops of wire on the torque of a simple motor. (U3AoS2)
- model the acceleration of particles in a particle accelerator (including synchrotrons) as uniform circular motion (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field). (U3AoS2)

Area of Study 3: How are fields used in electricity generation? (3AoS3)

Concepts used to model electricity.(U1AoS3)⁴

- apply concepts of charge (Q), electric current (I), potential difference (V), energy (E)⁵ and power (P), in electric circuits.(U1AoS3)
- analyse and evaluate different analogies used to describe electric current and potential difference (U1AoS3)
- investigate and analyse theoretically and practically electric circuits using the relationships:
$$I = \frac{Q}{t}, V = \frac{E}{Q}, P = \frac{E}{t} = VI.$$
(U1AoS3)
- justify the use of selected meters (ammeter, voltmeter, multimeter) in circuits (U1AoS3)

Circuit electricity (U2AoS3)

- model resistance in series and parallel circuits using: (U2AoS3)
 - current versus potential difference (I – V) graphs (U2AoS3)
 - resistance as the potential difference to current ratio, including $R = \text{constant}$ for ohmic devices (U2AoS3)

Using electricity (U2AoS3)

- investigate and apply theoretically and practically concepts of current, resistance, potential difference (voltage drop) and power to the operation of electronic circuits comprising resistors, ~~light bulbs, diodes, thermistors, light dependent resistors (LDRs), light emitting diodes (LEDs)~~ and potentiometers (quantitative analysis restricted to use of $I = \frac{V}{R}$ and $P = VI$) (U2AoS3)
- investigate practically the operation of simple circuits containing resistors, variable resistors, ~~diodes~~ and ~~other~~ non-ohmic devices .(U1AoS3)⁶
- describe energy transfers and transformations with reference to resistors, ... ~~light bulbs, diodes, thermistors, light dependent resistors (LDRs), light emitting diodes (LEDs)~~ and potentiometers⁷ ...~~in common devices~~ (U2AoS3)

⁴ The field concept, Electric-field, could be activated here to show why a current can flow. With some ingenuity, the elements of the photoelectric effect circuit could be introduced. Energy considerations between the plate and the collector in the phototube could then be discussed (E-field, potential difference, kinetic energy of electrons, energy needed to stop electrons crossing the gap). This would not be the place to discuss the reasons for the data; that can come in Unit 4 Area of Study 1

⁵ The “E” here is “energy”, which must not be confused with the electric field vector, “E” above.

⁶ Suggest an analysis of the phototube in the photoelectric effect circuit

⁷ See f/n6 above

Generation of electricity. (U3AoS3)

- calculate magnetic flux when the magnetic field is perpendicular to the area, and describe the qualitative effect of differing angles between the area and the field: $\Phi_B = B_{\perp}A$. (U3AoS3)
 - investigate and analyse theoretically and practically the generation of electromotive force (emf) including AC voltage and calculations using induced emf: $\varepsilon = -N \frac{\Delta\Phi_B}{\Delta t}$, with reference to:. (U3AoS3)
 - rate of change of magnetic flux. (U3AoS3)
 - number of loops through which the flux passes. (U3AoS3)
 - direction of induced emf in a coil. (U3AoS3)
- explain the production of DC voltage in DC generators and AC voltage in alternators, including the use of split ring commutators and slip rings respectively. (U3AoS3)
- describe the production of electricity using photovoltaic cells and the need for an inverter to convert power from DC to AC for use in the home (not including details of semiconductors action or inverter circuitry). (U3AoS3)

Transmission of electricity. (U3AoS3)

- compare sinusoidal AC voltages produced as a result of the uniform rotation of a loop in a constant magnetic field with reference to frequency, period, amplitude, peak-to-peak voltage (V_{p-p}) and peak-to-peak current (I_{p-p}). (U3AoS3)
- compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component. (U3AoS3)
- analyse transformer action with reference to electromagnetic induction for an ideal transformer: $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$. (U3AoS3)
- analyse the supply of power by considering transmission losses across transmission lines. (U3AoS3)

Unit 4: How have creative ideas & investigation revolutionised thinking in physics?

Area of Study 1: How has understanding about the physical world changed? (U4AoS1)

Electromagnetic radiation (U1AoS1)

- identify all electromagnetic waves as transverse waves travelling at the same speed, c , in a vacuum as distinct from mechanical waves that require a medium to propagate (U1AoS1): identify that all electromagnetic waves travel at the same speed, c , in a vacuum. (U4AoS1)
- describe light as a transverse electromagnetic wave which is produced by the acceleration of charges, which in turn produces changing electric fields and associated changing magnetic fields. (U4AoS1)
- identify the amplitude, wavelength, period and frequency of waves (U1AoS1)
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$ (U1AoS1)
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source) (U1AoS1)

- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared (U1AoS1)
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society (U1AoS1)
- explain the formation of a standing wave resulting from the superposition of a travelling wave and its reflection. (U4AoS1)
- analyse the formation of standing waves (only those with nodes at both ends is required). (U4AoS1)
- investigate and explain theoretically and practically diffraction as the directional spread of various frequencies with reference to different gap width or obstacle size, including the qualitative effect of changing the $\frac{\lambda}{w}$ ratio, and apply this to limitations of imaging using electromagnetic waves. (U4AoS1)
- explain the results of Young's double slit experiment with reference to:. (U4AoS1)
 - evidence for the wave-like nature of light. (U4AoS1)
 - constructive and destructive interference of coherent waves in terms of path differences:
 $n\lambda$ and $\left(n + \frac{1}{2}\right)\lambda$ respectively, where $n = 0, 1, 2, \dots$ (U4AoS1)
 - effect of wavelength, distance of screen and slit separation on interference patterns:
 $\Delta x = \frac{\lambda L}{a}$ when $L \gg d$. (U4AoS1)

Light as a particle. (U4AoS1)

- apply the quantised energy of photons: $E = hf = \frac{hc}{\lambda}$. (U4AoS1)
- analyse the photoelectric effect with reference to:. (U4AoS1)
 - evidence for the particle-like nature of light. (U4AoS1)
 - experimental data in the form of graphs of photocurrent versus electrode potential, and of kinetic energy of electrons versus frequency. (U4AoS1)
 - kinetic energy of emitted photoelectrons: $E_{k\max} = hf - \phi$, using energy units of joule and electron-volt. (U4AoS1)
 - effects of intensity of incident irradiation on the emission of photoelectrons. (U4AoS1)
- describe the limitation of the wave model of light in explaining experimental results related to the photoelectric effect. (U4AoS1)

Matter as particles or waves. (U4AoS1)

- interpret electron diffraction patterns as evidence for the wave-like nature of matter. (U4AoS1)
- distinguish between the diffraction patterns produced by photons and electrons. (U4AoS1)
- calculate the de Broglie wavelength of matter: $\lambda = \frac{h}{p}$. (U4AoS1)

Similarities between light and matter. (U4AoS1)

- discuss the importance of the idea of quantisation in the development of knowledge about light and in explaining the nature of atoms. (U4AoS1)
- compare the momentum of photons and of matter of the same wavelength including calculations using: $p = \frac{h}{\lambda}$. (U4AoS1)
- explain the production of atomic absorption and emission line spectra, including those from metal vapour lamps. (U4AoS1)
- interpret spectra and calculate the energy of absorbed or emitted photons: $E = hf$. (U4AoS1)
- analyse the emission or absorption of a photon by an atom in terms of a change in the electron energy state of the atom, with the difference in the states' energies being equal to the photon energy:
 $E = hf = \frac{hc}{\lambda}$. (U4AoS1)
- interpret the single photon and the electron double slit experiment as evidence for the dual nature of light and matter. (U4AoS1)

Einstein's special theory of relativity. (U4AoS1)

- describe the limitation of classical mechanics when considering motion approaching the speed of light. (U4AoS1)
- describe Einstein's two postulates for his special theory of relativity that: (U4AoS1)
 - the laws of physics are the same in all inertial (non-accelerated) frames of reference. (U4AoS1)
 - the speed of light has a constant value for all observers regardless of their motion or the motion of the source. (U4AoS1)
- interpret the null result of the Michelson-Morley experiment as evidence in support of Einstein's special theory of relativity. (U4AoS1)
- compare Einstein's special theory of relativity with the principles of classical physics. (U4AoS1)
- describe proper time (t_0) as the time interval between two events in a reference frame where the two events occur at the same point in space. (U4AoS1)
- describe proper length (L_0) as the length that is measured in the frame of reference in which objects are at rest. (U4AoS1)
- model mathematically time dilation and length contraction at speeds approaching c using the equations: $t = \gamma t_0$ and $L = \frac{L_0}{\gamma}$ where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$. (U4AoS1)
- explain and analyse examples of special relativity including that: (U4AoS1)
 - muons can reach Earth even though their half-lives would suggest that they should decay in the upper atmosphere. (U4AoS1)
 - particle accelerator lengths must be designed to take the effects of special relativity into account. (U4AoS1)
 - time signals from GPS satellites must be corrected for the effects of special relativity due to their orbital velocity. (U4AoS1)

Relationship between energy and mass. (U4AoS1)

- interpret Einstein's prediction by showing that the total 'mass-energy' of an object is given by:
 $E_{\text{tot}} = E_k + E_0 = \gamma mc^2$ where $E_0 = mc^2$, and where kinetic energy can be calculated by:
 $E_k = (\gamma - 1)mc^2$. (U4AoS1)
- apply the energy-mass relationship to mass conversion in the Sun, to positron-electron annihilation and to nuclear transformations in particle accelerators (details of the particular nuclear processes are not required). (U4AoS1)

Area of Study 2: How is scientific inquiry used to investigate fields, motion or light? (U4AoS2)

Investigation design (U4AoS2)

- identify the physics concepts specific to the investigation and explain their significance, including definitions of key terms and physics representations
- explain the characteristics of the selected scientific methodology and method including: techniques of primary qualitative and quantitative data generation relevant to the selected investigation; and appropriateness of the use of independent, dependent and controlled variables in the selected scientific investigation
- identify and apply concepts of accuracy, precision, repeatability, reproducibility, resolution and validity of data; and the identification of, and distinction between, error and uncertainty
- identify and apply health, safety and ethical guidelines relevant to the selected investigation.

Scientific evidence (U4Ao2)

- discuss the nature of evidence that supports or refutes a hypothesis, model or theory
- apply methods of organising, analysing and evaluating primary data to identify patterns and relationships including: the physical significance of the gradient of linearised data; causes of uncertainty; use of uncertainty bars; and assumptions and limitations of data, methodologies and methods
- model the scientific practice of using a logbook to authenticate generated primary data

Science communication (U4AoS2)

- apply the conventions of science communication: scientific terminology and representations; symbols, equations and formulas; standard abbreviations; significant figures; and units of measurement
- apply the conventions of scientific poster presentation, including succinct communication of the selected scientific investigation, and acknowledgement of reference
- explain the key findings and implications of the selected investigation.