PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	In this programme, formulae cited in the text are derived, and pupils should, if asked, be capable of deriving them, whereas **Formulae and definitions given in boxes should be known by pupils, and may be quoted without proof.** **Bold Type** is used in this text to denote vector quantities.	
Section M. Mechanics. **M1 Kinematics.** **M1.1 Vector representation.** **M1.2 Uniform and uniformly accelerated motion.**	Displacement from a specified origin, velocity, and acceleration all behave in accordance with a vector model. Revision of definitions and relationships in basic kinematics, see programme of years 4 and 5, sections K2, K3, introducing the **vector nature** of these quantities. **Velocity** Symbol: $\boldsymbol{v}$ Unit: ms^{-1} Definition: $\boldsymbol{v} = \Delta \boldsymbol{s}/\Delta t$ Instantaneous velocity $= \lim_{\Delta t \to 0} (\Delta \boldsymbol{s}/\Delta t) = d\boldsymbol{s}/dt$ **Acceleration** Symbol: $\boldsymbol{a}$ Unit: ms^{-2} Definition: $\boldsymbol{a} = \lim_{\Delta t \to 0} (\Delta \boldsymbol{v}/\Delta t) = d\boldsymbol{v}/dt$ **Average velocity** Symbol: $\langle \boldsymbol{v} \rangle$ or $\overline{\mathbf{v}}$ Definition: $\langle \boldsymbol{v} \rangle$ = *Total vector displacement/Total time* **Equations of uniformly accelerated motion:** $\boldsymbol{v} = \boldsymbol{v_0} + \boldsymbol{a}t$ $\boldsymbol{s} = \boldsymbol{v_0}t + \boldsymbol{a}t^2/2$	$v^2 = u^2 + 2as$

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
M1.3 Combination of velocities.	Addition and resolution of uniform velocities in two dimensions.	Practical investigations; air table, stroboscope..... Trigonometrical or vectorial treatment. Drift velocity: tides, currents, air- and ground speeds
M1.4 Projectile movement. ***Time: 16 periods (M1)***	Addition of two perpendicular velocities, one of which is uniform and the other uniformly accelerated. This situation obtains when a **projectile** moves without air resistance under gravity, and results in a parabolic path. Pupils should be able to relate later velocities, positions and directions to initial conditions, time of flight etc.	
M2 Dynamics. **M2.1 Basics.**	Revision of basic dynamics, see 4th and 5th year programmes sections M4.1 to M4.5, introducing and underlining the vector nature of force. Addition and resolution of forces in two dimensions. The work should be limited to a consideration of point or point-like bodies. $\mathbf{F}_{res} = \Sigma \mathbf{F}$ $\mathbf{F}_{res} = 0 \iff \mathbf{v} = constant$ $\mathbf{F}_{res} = m\mathbf{a}$ $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$	
M2.2 The elastic force.	In addition to the forces already studied, the **elastic** or **spring** force should be introduced. The extension of a stretched spring is proportional to its tension. **Elastic Force.** $\mathbf{F} = -k\Delta\mathbf{s}$ where k is known as the spring constant. Connected systems such as lifts, towed and towing vehicles etc should be treated, as should movement under non-parallel systems of forces, e.g. on the inclined plane.	Experiments in trains, lifts, rockets etc. Bodies falling in water,

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
M2.3 Dissipative force.	A qualitative discussion of the effect of dissipative forces (solid and fluid friction) should be included.	parachute Final speed of falling bodies
M2.4 Universal gravitation.	Two spherically symmetrical bodies of mass M and m whose centres of mass are separated by a distance d attract mutually, with a force proportional to their masses and inversely proportional to the square of their separation. **Gravitational Force.** $|\mathbf{F}| = Gm_1m_2/d^2$ where G is the universal gravitational constant.	Cavendish's balance.
M2.5 Variation of *g*. ***Time: 10 periods (M2)***	At a distance r from a planet of mass M the value of the gravitational intensity is $g = GM/r^2$; if g_0 is the value at the surface (radius R) then $g/g_0 = R^2/r^2$. The treatment extends only to point masses or masses with spherical symmetry. The inverse square field, e.g. of a planet, for vertical displacements which are trivial compared with radius, approximates to a uniform field.	
M3. Conservation laws. **M3.1 Energy**	Macroscopic interactions and reactions result in no overall change of total energy, though there may be exchange or conversion from one form of energy to another. The work done by the resultant force acting on any body is equal to the change in its kinetic energy. $W = \mathbf{F}\cdot\Delta\mathbf{s}$ $W = \Delta E_k = \Delta(m\mathbf{v}^2/2)$ Near the surface of the Earth the gravitational force may be considered to be constant, thus gravitational potential energy is proportional to height above a given datum. The work done by an elastic force is the product of average force and displacement.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	$W_g = \Delta E_g = \boldsymbol{F}\cdot\Delta\boldsymbol{s} = m\boldsymbol{g}\cdot\boldsymbol{h}$ $W_{el} = \langle\boldsymbol{F}\rangle\cdot\Delta\boldsymbol{s}$ **For an initially unstretched spring** $W_{el} = \Delta E_{el} = \frac{1}{2}\boldsymbol{F}\cdot\Delta\boldsymbol{s} = \frac{1}{2}k\,\Delta\boldsymbol{s}^2$	Energy exchange in a weight bobbing on a spring Rollercoasters
	In the absence of friction, the sum of a body's kinetic energy and its potential energies associated with such forces as the gravitational and the elastic force is constant (sometimes known as the **mechanical energy** of the body). The vectorial aspects of the calculation of work should be emphasized, and cases where the force and displacement are non-parallel should be treated. Pupils should be able to cope with energy conservation and transfer in situations involving exchange of energy under all the forms met in the programmes of years 4 and 5.	
M3.2 Momentum.	A steady force $\boldsymbol{F}_{res}$ acting for a time Δt on a body modifies its velocity. $\boldsymbol{F}_{res}\,\Delta t = m\Delta\boldsymbol{v}$ *(constant mass)*	
	It follows that if the resultant force is zero the quantity m**v** is a conserved quantity. This is the **momentum** of the body. The left hand side of this equation is the **Impulse** of a force. [**Note:** *Care is needed in the translation of "Impulse" (= Kraftstoss) and "Momentum" (= Impuls) into and from German and some other languages.*]	It may be possible with a fast group, where the thermodynamics option has not been chosen, to look at gas pressure here.
	Momentum Symbol $\boldsymbol{p}$ Unit kg ms^{-1} $\boldsymbol{p} = m\boldsymbol{v}$	Experimental study of explosions and collisions. "Newton's cradle".

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	For a system of two or more bodies to which all forces are internal, the **law of action and reaction implies that the sum of momenta is constant**. These laws may be written in terms of momentum in a more fundamental way.	Recoil of artillery; landing gear; rocket engine; seat belts; water jets.
	$\mathbf{F}_{res} = d\mathbf{p}/dt$ in general $= m\mathbf{a}$ (constant mass) $\Sigma m_n \mathbf{v}_n$ = constant (for a closed system)	However, able groups might look at variable mass systems e.g. rockets in flight.
	No quantitative work on systems of variable mass is required.	
M3.3 Collisions. ***Time: 16 periods (M3)***	A collision subsequent to which bodies adhere and thus move together is called a **perfectly inelastic collision**. A collision which conserves kinetic energy is called a **perfectly elastic collision**. Both should be studied, in one and in two dimensions. The law of conservation of momentum, being based on the law of action and reaction, applies to both categories. Kinetic energy is dissipated as heat in an inelastic collision.	Gramophone turntables; rotation and revolution of the Earth.
M4 Uniform circular motion. **M4.1 Basics.**	The movement of a point moving around another (fixed) point may conveniently be described by the angle, in radians, swept out in a given time, and by the radius. The angle described per second is the angular velocity. It is not essential at this level to insist on the vectorial character of angle or of angular velocity.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	Angle Symbol: θ Unit: radian rad Definition: $\theta = d/r$ *(d = arc length, r = radius)* **Angular velocity** Symbol: ω Unit: rad s^{-1} or s^{-1} Definition: $\omega = \Delta\theta/\Delta t$ $\omega = v/r$ $\boldsymbol{T} = 2\pi/\omega = 1/f$	Experimental verification Centrifuge, spin dryer, Coriolis force. Planetary movement. Weight at poles and equator Conical Pendula etc
M4.2 Centripetal force.	A resultant force is required to cause such a body to perform uniform circular motion, since such a body cannot be in equilibrium. This force must be directed towards the centre of the circle, and therefore causes an acceleration towards the centre. The acceleration required to produce a given circular trajectory depends on the values of radius and angular speed required. The force producing this acceleration is called the **centripetal force**. $a_{cent} = v^2/r = \omega^2 r$ $F_{cent} = mv^2/r = m\,\omega^2 r$	For completeness, Kepler's laws might be noted, but it will be difficult to tie them in with the rest of the course unless the "rotating bodies" option is taken.
M4.3 Satellite motion.	The movement of a satellite under the gravitational force can result in a circular orbit, whose period is given by $T^2 = 4\pi^2 r^3/GM$, where M is the mass of the central body. Thus the mass of the satellite is irrelevant.	
M4.4 Frames of reference. ***Time: 8 periods (M4)***	An observer in a rotating frame of reference observes an "inertial force" known as the **centrifugal force**. Teachers may use methods based on this or on centripetal force to resolve problems on circular motion, as they choose.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
M5 Simple Harmonic motion. **M5.1 Basics.**	A body is said to perform **simple harmonic motion** if a "restoring" force exists which is always directed towards a fixed point, and is proportional in magnitude to the body's distance from this point. An equivalent definition is that the body's displacement from a fixed point varies sinusoidally with time. Pupils should be able to demonstrate the equivalence of these statements. Examples of simple harmonic or approximately simple harmonic motion include the bob of the simple pendulum and the movement of a mass under the elastic force, with or without the action of gravity. If the sum of kinetic and potential energies is constant the amplitude of the motion will be independent of time, and the motion is said to be **undamped**. If this is not the case, then the amplitude decreases with time giving damped simple harmonic motion (usually due to frictional forces of some kind). **Simple Harmonic Motion** Definition: $F = -kx$ or $x = A \sin \omega t$ $(k>0)$ Velocity: $v = A\omega \cos \omega t$ Acceleration: $a = -A\omega^2 \sin \omega t = -\omega^2 x$ where $\omega = 2\pi f = 2\pi / T$ Energy: $E = ½mA^2\omega^2$	Refer to 3.1 above. $v = \omega(A^2 - x^2)^{½}$
M5.2 Energy exchange between oscillators. *Time: 10 periods (M5)*	An oscillator can communicate its movement to another which is linked to it in some way. If the two oscillators have the same period, the response of the second can readily result in small stimuli producing significant movement. This phenomenon is known as **resonance**. Examples and applications should be explored but a quantitative investigation is not required.	The similarity between gravitational and electric fields may be exploited
Section F. Electric and magnetic fields. **F.1 The electric field.** **F1.1 Basics.**	An **electric field** is said to exist in a region of space where a body experiences a force proportional to its electric charge. The direction of the electric field is in the direction of the force observed on a positive test charge. The intensity of the field is the force observed per unit test charge.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	Electric field intensity Symbol: $\boldsymbol{E}$ Unit: NC^{-1}, Vm^{-1} Definition: $\boldsymbol{E} = \boldsymbol{F}/Q$	Electric field line maps Equipotentials
F1.2 Uniform electric field.	A **uniform field** is said to exist when the magnitude and direction of **E** are constant within a region. A good approximation to a uniform electric field is observed between two parallel conducting plates with a potential difference between them.	
F1.3 Electrical potential and potential energy.	The definition of electric field implies that a charge moving parallel to the direction of an electric field will gain or lose energy. This energy is known as electrical potential energy. The definitions of **potential difference** (commonly called **voltage**), work and electric intensity lead to simple formulae for the value of the work done in the course of such movement. **Work done in an electric field** $W = Q\,\Delta U$ $= \boldsymbol{F}\cdot\Delta\boldsymbol{s} = \boldsymbol{E}\cdot Q\Delta\boldsymbol{s}$ *if the field is uniform.* The electrical **potential** at a point is the electrical potential energy per unit charge situated at that point. As is normal when dealing with potential energy, the point at which electrical P. E. is taken as zero is arbitrary. Common conventions are that a) test charges at a very large distance from any other body, or b) test charges situated on a conductor connected to the earth are taken as possessing zero potential energy, and that therefore the points at which such charges are situated may be taken to be at zero potential. Thus the basic equation shown above may be rewritten in terms of potentials rather than potential differences. It is necessary to distinguish work done by the field from work done by an external agent moving a test charge against the field direction.	A fast group may be able to approach the idea of a calculus formulation of this topic. Discussion of the sign of W_{AB}

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	Electrical Potential $U_A = E_A/Q$ whence the work done to move a charge in an electric field is $W_{AB} = Q(U_B - U_A)$	It may be possible to treat the capacitance and potential due to an isolated sphere.
F1.4 The radial electric field.	A point charge (or a spherically symmetrical distribution of charge, eg a charged conducting sphere) is surrounded by an electric field whose intensity depends directly on the total charge and inversely on the square of the distance from the point. The intensity of this field also depends on a property of the medium in which the charge is placed, defined as its **permittivity.**	
	Intensity due to a point charge. $E = Q/4\pi\varepsilon r^2$ **Permittivity** The quantity ε is the permittivity of the medium in which the experiment is conducted. **Relative Permittivity** Symbol: ε_r Unit: None Definition: $\varepsilon_r = \varepsilon/\varepsilon_0$	The comparison with gravity may again be exploited. Coulomb's experiment Practical work with batteries, electrolytic capacitors and resistances.
	There is an inverse square law of force between two point charges Q_1 and Q_2 separated by a distance r.	
Time: 16 periods (F1)	**Force between two point charges** $\mathbf{F} = \mathbf{E}Q = Q_1Q_2/4\pi\varepsilon r^2$	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
F.2 Capacitance. **F2.1 Basics.**	Any conductor may be charged, and as a consequence change its potential. If a system consists of two conductors which are initially at the same potential, charge may be transferred from one to the other by some outside agent (e.g. a battery or a power supply), causing the p.d. between the plates to increase. This p.d. is found to be proportional to the amount of charge transferred. The ratio is defined as the **capacitance** of the system, and it depends on the dimensions of the conductors and on other parameters of the system. **Capacitance** Definition: $C = Q/U$ Unit: farad $F = CV^{-1}$	Capacitor flash, electret and capacitor microphones, smoothing. Water container analogy
F2.2 The parallel plate capacitor.	Two parallel plates, separated by an insulator, constitute a capacitor of particular interest, whose capacitance is a simple function of the area of the plates, their separation and the permittivity of the insulator separating them. **Capacitance of a parallel plate capacitor** Relation: $C = \varepsilon A/d$ whence $\varepsilon = Cd/A$ and hence ε may be expressed in Fm^{-1}	
F2.3 Energy storage.	Work is done in charging the capacitor, and energy is stored in a charged capacitor as electrical potential energy, which can be recovered on discharge. The stored energy is calculated using the mean value of the voltage during the charging process. **Energy stored in a charged capacitor** $E = ½ QU = ½ CU^2 = ½ Q^2/C$	Possible mathematical formulation of the exponential law, if the level of the class permits.

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
F2.4 Time to charge and discharge a capacitor.	The energy stored in such a system may be compared in many ways with that stored in a stretched spring, see above. The idea of an exponential charging process should be introduced informally. Pupils should be aware that the time to charge a capacitor to a certain proportion of the supply voltage is proportional to capacitance and resistance, and that this allows capacitors to be used as timing devices. A meaningful **time constant** may be calculated depending only on resistance and capacitance values.	
F2.5 Capacitors in combination. ***Time: 8 periods (F2)***	The combined capacitance of parallel capacitors is equal to their sum, whereas in a series circuit, adding more capacitive elements reduces the effective capacitance. **Parallel Circuit:** $C = C_1 + C_2 + C_3 + ...$ **Series Circuit:** $1/C = 1/C_1 + 1/C_2 + 1/C_3 + ...$ **Time Constant:** $T = RC$	A group who are very good at vector mathematics might manage a rigorous treatment.
F 3. The magnetic field.	*Formulae associated with electromagnetism are given in "scalar form", i.e. without an attempt to express them rigorously with vectors.*	The Biot-Savart law may be introduced.
F3.1 Basics.	The work from year 5 on the basic magnetic fields due to a current-carrying wire etc. should be revised, again emphasizing vector aspects of the material.	
F3.2 The current element.	A **current element** (i.e. an infinitesimally short wire carrying a current) placed in a magnetic field experiences a force, proportional to the current and to the length of the element, which varies with the **intensity of the magnetic field.** This permits a measure of the intensity or **magnetic induction** of the magnetic field, as the force per unit current per unit length. The sense and orientation of the current element with respect to the magnetic field also indicate the direction of the field.	

PROGRAMME HEADING	MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".	AVENUES OF APPROACH
	Magnetic Induction or **Magnetic Flux Density.** Symbol B Unit: tesla T = $NA^{-1}m^{-1}$ $F = B\,i\,\Delta L \sin\theta$	Experimental work.
F3.3 The uniform magnetic field. The solenoid.	In the middle of a long solenoid, the magnetic induction is uniform and depends on the current and on the number of turns per metre of length. It also depends on a property of the medium inside the solenoid, known as its **permeability.** **Magnetic Induction due to a solenoid.** $B = \mu ni = \mu Ni / l$ For a vacuum (or approximately for air) $\mu = \mu_0 = 4\pi \times 10^{-7}\ TA^{-1}m^{-1}$ **Permeability** The quantity μ is called the *permeability* of the medium in which the experiment is conducted. **Relative Permeability** Symbol: μ_r Unit: None Definition: $\mu_r = \mu / \mu_0$	Hall voltage is the product of B, carrier velocity and breadth of the conductor. In doped semiconductors and in fluids the carriers may be of either or both signs.
F3.4 Moving charges in a magnetic field.	Free charged particles moving perpendicular to a magnetic field also constitute a current and experience the force described in 3.2 above. Hence charge carriers traversing a conductor placed normal to a magnetic field experience a deflection giving rise to the maintenance of a p.d. across the conductor, known as an **emf.** The direction of this p.d. permits the sign of the majority charge carrier to be determined; in conductors, the majority charge carriers are found to be negatively charged. A practical rule to determine the direction of the emf should be taught.	It is not appropriate to insist on the technical definitions of flux and induction, which would require the weber's definition to come before that of the tesla. A capacity to work with these quantities is sufficient.

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
F3.5 Electromagnetic induction.	**Moving charge in a magnetic field.** $F = Bqv\sin\theta$ The magnetic induction may profitably be pictured as consisting of lines of **magnetic flux** (ϕ) whose **density** is equal to the magnetic induction. If a wire is moved perpendicular to a magnetic field there will be an emf induced across it. This emf is also present when the flux linking a closed circuit varies, and these two processes may be thought of as equivalent. The phenomenon is known as **electromagnetic induction**. Conservation of energy implies that any resulting current is in such a direction as to oppose the change responsible for producing it. The action of the dynamo uses this phenomenon. **Magnetic Flux.** Symbol ϕ Unit: weber Wb = Tm^2 = Vs $B = \phi / A$ where $B \perp A$ **Induced emf** $U = -\Delta\phi/\Delta t = -A\Delta B/\Delta t = Bvl$ [**Note:** *Care is needed in translations of the term emf, which seems not to be used in modern textbooks in several languages.*] A varying current in a solenoid will cause a varying magnetic field along its axis, which will also link any adjacent closed circuit. Thus an emf will be induced in the solenoid itself proportional to the rate of change of current (**self-induction**) and in the adjacent but electrically unconnected circuit (**mutual induction**). The action of the transformer relies on mutual induction.	If the a.c. option is not chosen, there may still be time with an able group to look at power transmission.

PROGRAMME HEADING	MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".	AVENUES OF APPROACH
Time: 16 periods (F3). *Section O. Optional topics. One of these topics should be chosen for study.*	**Self and Mutual Inductance.** Symbol L, M Unit henry H = VsA^{-1} = $Wb\ A^{-1}$ *In one circuit,* $U \propto d\phi/dt = -L di/dt$ *Between two circuits,* $U \propto d\phi/dt = -M di/dt$	$\omega^2 = \omega_0^2 + 2a\theta$
01. The mechanics of rotating rigid bodies.	Conditions of the equilibrium of a rigid body: the Principle of Moments. Rotational Kinematics; angular velocity ω, angular acceleration α $\omega = \omega_0 + \alpha t$ $\theta = \omega_0 t + ½ \alpha t^2$ $\theta = ½(\omega_0 + \omega)t$ *etc.* Rotational kinetic energy and the Moment of Inertia. $I = \Sigma mr^2$ $E_K = ½I\omega^2$ The moments of inertia of simple bodies: point, hoop, disc, rod, sphere. The parallel axis theorem. $I = I_{CM} + Md^2$ Rotational dynamics and torque T. $T = I\alpha$ $T\Delta t = \Delta I\omega$	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	Angular Momentum and its conservation. $L = I\omega$ **[Note:** *A simple treatment, restricted to 2 dimensions, may ignore the vector nature of torque and treat it as a positive or negative quantity, according to its clockwise or anticlockwise sense. This does not of course exclude the full use of* $\mathbf{T} = \mathbf{r} \times \mathbf{F}$ *and of the vector nature of angular quantities with a fast group.*]	
O2. A.C. circuits. **O2.1. Production of an A.C.**	When a coil turns in a homogeneous magnetic field, a sinusoidal alternating current is produced. $U(t) = U_0 \sin \omega t$ $\omega = 2\pi f = 2\pi/T$	
O2.2. Effective values of current and voltage.	The effective value (r.m.s. value) of an alternating voltage or current is the value of the D.C. equivalent which would dissipate the same average power. Thus for sinusoidal waveforms $I_{eff} = I_0/\sqrt{2}$ $U_{eff} = U_0/\sqrt{2}$	
O2.3. Phase angle difference between U and I. Impedance. Frequency dependence.	The impedance Z of an electric component or circuit is defined as $Z = U_0/I_0 = U_{eff}/I_{eff}$. For a pure resistance $Z = R$, but for reactive components (inductors or capacitors) the impedance is frequency dependent, and a difference of phase angle $\Delta\phi$ is observable between U and I. $Z_C = 1/\omega C$ $\Delta\phi = -\pi/2$ *(U lags on I)* $Z_L = \omega L$ $\Delta\phi = \pi/2$ *(U leads on I)* These phenomena may be studied with an oscilloscope.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
O2.4. The L–C–R series circuit.	Experimental study of a series circuit consisting of resistance, capacitor and inductor shows that at low and high frequencies, one of the reactive terms (Z_C or Z_L) dominates, causing a net phase angle difference which is correspondingly positive or negative. $Z = \sqrt{[R^2 + (Z_c - Z_L)^2]}$	
O2.5. Resonance. The oscillator.	At a particular frequency Z becomes purely resistive and the phase angle difference is zero. This **resonance** phenomenon is characterized by a sharply peaked minimum of impedance. The **resonant frequency** is given by $\omega = 1/\sqrt{(LC)}$ In an ideal situation where R = 0, we would obtain Z = 0 at resonance. Consequently self-sustained oscillations would occur if the driving generator were to be replaced by a short circuit.	
O3. Kinetic Theory and Thermodynamics.		
O3.1 Basics. Absolute Zero.	Revision of 5th year work. Heat (internal) energy of molecules, temperature. The definite amount of internal energy possessed by a body implies that energy cannot be removed without limit, and suggests that there may be a limit also to how low temperature can be.	
O3.2 Properties of temperature.	Temperature difference is the factor which causes energy to move from one body to another.	
O3.3 The zeroth law of thermodynamics.	If two bodies are at the same temperature as a third, they are at the same temperature as each other. They do not necessarily possess the same amount of internal energy.	
O3.4 Model of the ideal gas and its real approximation. Absolute zero.	Pressure of an ideal gas; simple derivation from elementary ideas of pressure and momentum of the expression for the pressure of such a gas. $P = (Nm \langle c^2 \rangle)/3$, where P is the gas pressure, N the number of molecules and m the molecular mass.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	This relation implies that *PV* is proportional to mc^2 , which may be considered to be proportional to internal energy and thus to temperature in a simple model of constant specific heat capacity. Such a model implies an absolute zero of temperature which may be calculated as – 273°C approximately. In a real gas at low pressure with a large mean free path this is found to be the case to a good approximation. *PV/T has a constant value for a given mass of gas.*	
O3.5 Reversibility. Organization and entropy.	Some changes in nature (burning, levelling, mixing.....) obviously cannot be reversed without providing significant amounts of energy. All real mechanical operations involve dissipative forces of some sort, and waste some energy as heat to the environment. Apparently reversible changes (pendulum) are only approximately so. All natural changes show a tendency to change from highly organized to states to states which are less so. The quantity **entropy** measures the amount of disorder in a system. Entropy increases in natural, “irreversible” processes.	
O3.6 The second law of thermodynamics	Work can be completely converted to heat but heat cannot be completely converted to work. Thus the world is gaining heat energy all the time, and without some organizing agent can never lose it again. This is the **second law of thermodynamics** and is equivalent to stating that heat energy cannot by itself “run uphill” from a body at low temperature to a body at high temperature (this would result in increased entropy).	
O3.7 Gas engines; trading heat for work. The first law of thermodynamics.	Internal energy of a gas can be partly traded for work. A sink for waste heat is required as well as a source of high grade heat, in accordance with experience and in agreement with the second law. It is a theoretical impossibility to invent a car engine which does not heat the world up, both through friction and from some of the energy provided by the fuel.	
O4. Special Relativity. **O4.1 The principle of relativity.**	Motion observed within and from outside moving systems; the idea of an inertial frame.	
O4.2 The velocity of light.	Einstein assumed that the speed of light is constant in all inertial systems. Experiment supports this assumption. The velocity of light is a universal natural constant.	

PROGRAMME HEADING	*MATERIAL AND IDEAS TO BE COVERED: definitions, units, formulae and "Savoir-Faire".*	*AVENUES OF APPROACH*
	The constancy of the speed of light has consequences for the quantities of length, time and mass in different inertial systems.	
O4.2.1 Time dilation.	To an observer moving with a velocity *v* relative to an inertial frame, events in that inertial frame occur more slowly than they would to an observer who is stationary in it. The observed time interval Δt is related to the so-called proper time interval Δt_0. $\Delta t = \Delta t_0/[1 - (v/c)^2]^{½}$	
O4.2.2 Length contraction.	Likewise, observed distances in a direction parallel to the relative velocity ***v*** are shortened by a factor k (the FitzGerald-Lorentz contraction) $\Delta l = \Delta l_0\, [1 - (v/c)^2]^{½}$	
O4.2.3 Mass-energy equivalence.	The mass of a body depends on its velocity relative to the observer: $m = m_0 / [1 - (v/c)^2]^{½}$ Generally a mass m is equivalent to an amount of energy E, which allows the classical laws of conservation of energy and of mass to be assimilated into one single law $E = m\, c^2$	
Time 12 periods (O)	The increase of mass Δm of a moving body corresponds to the amount of kinetic energy E_k which it possesses: $\Delta m = E_k/c^2$	