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Section M. Mechanics. **M1. Force.** **1.1 Basic notions**.	**PART 1. 4TH YEAR PROGRAMME.** A **force** is identified by its effects: it can change the state of movement of things, or change their shape. Forces can be measured by observing the extension caused in a spring. Pupils should recognise some common forces and know about their behaviour: **Gravity force**: attracts all massive objects towards the earth with a force of 10 Newtons per kilogramme of mass approximately. Varies with geographical situation. **Contact force:** acts between two surfaces in contact, which repel each other because of their proximity. Direction normal to the common surface. **Friction force**: acts parallel to a common surface, so as to resist movement or attempts at movement. Qualitative study. **Force** Symbol: F Unit: Newton N *Force of Gravity* $F_g = m \cdot g$ *At the Earth's surface, "g"* $\approx$ *10* N/kg **Time: 6 periods (M1)**	Other forces might include muscular forces and magnetic forces. Graphical methods and slopes may be conveniently introduced. The coefficient of friction can be studied by pupils who work fast, as might the idea of addition of non-parallel forces.
M2. Work, power, and energy. **2.1 Terminology.** **2.2 Work.**	The physical meanings of these terms must be distinguished from their everyday meanings. **Work** is done when a force moves its point of application. (Examples should be limited to	

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	displacements parallel to the direction of the force, and should include work done in lifting and in sliding.) No work is done when the displacement is perpendicular to the direction of the force. **Work** Symbol: W Unit: Joule J = N·m Definition: $W = F\cdot\Delta x$ *when* $F \parallel \Delta x$ Note: $W = 0$ *when* $F \perp \Delta x$	Lifting experiments might include work with pulleys and/or levers, and the inclined plane may be included, with or without (according to level) the notion of composition of forces.
2.3 Energy.	**Energy** is the capacity to do **work**. **General note:** *The teaching of energy should pervade all teaching during years 4 and 5. Teachers may introduce the different forms of energy at different points in the programme, and some of them will be treated at more than one point. This programme accordingly lays down no strict order for introducing these different forms, provided that all the forms of energy described are dealt with before the end of the 5th year.*	
2.4 Relation between work and energy.	When work is done, an equivalent amount of energy is converted from one form to another. This energy is therefore also measured in Joules. It can take many forms e.g. kinetic, chemical potential, gravitational potential, etc. The loss of any energy of one form is accompanied by an equal increase in other forms. This is the **principle of conservation of energy.** **Energy** Symbol: E Unit: Joule J Practical unit: Kilowatt.hour kWh (non-S. I.) $\Delta E = -W$ Note: *Gravitational potential energy* $E_p = m\cdot g\cdot h$	A good group might consider also the elastic potential energy stored in a stretched spring or elastic cord, introducing another graphical solution and the idea of the average of a linearly varying force.

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2.5 Power.	**Power** may be presented as the energy transferred each second. The concept of power leads to the introduction of the **kWh** as a practical unit of energy. **Power** Symbol: P Unit: Watt W = J/s. Definition: $P = \Delta E/\Delta t = W/\Delta t$	Possible experiments include stair-climbing and the bicycle ergometer. Sports applications (high jump, shotput) may be considered, also e.g. power output of a climbing aircraft or a weight driven clock.
2.6 Efficiency.	In a perfectly efficient operation, the useful energy produced would be equal to the total energy expended. In practice, a certain proportion of the energy expended is wasted. The proportion of energy usefully converted is called the **efficiency**. **Efficiency** Symbol: η Definition: $\Delta E_{usefully\ produced} = \eta \cdot \Delta E_{expended}$ $(\eta \leqslant 1)$ **Time: 8 periods (M2)**	Human muscle efficiency (of the order of 25%) may be considered.
M3. Pressure.		
3.1 Basic notion.	A force whose effect is distributed over and normal to a surface defines a **pressure**. Introduced as Newtons of force on each unit of area.	Hydraulic ram.

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3.2 Hydrostatic pressure.	Because of the force of gravity acting on them, liquids and gases exert a pressure whose magnitude depends (as well as on the intensity of the gravitational force) directly on the depth and on the density of the fluid. This force acts equally in all directions. The difference of pressure on the upper and lower surfaces of a body gives rise to an **upthrust**. **Pressure** Symbol: *P* Unit: Pascal Pa Definition: $P=F/A$ **Time: 6 periods (M3)**	Hydraulic brakes: Archimedes upthrust and flotation. Atmospheric pressure; the "ocean of air".
Section K. The study of movement. **K1. Uniform movement.**	When an object moves with **constant velocity**, it covers equal distances in a straight line in equal times. The magnitude of the velocity is introduced as the distance travelled each second. The graph of distance against time is a straight line.	Air track and rail experiments; ticker-timer experiments.
K2. Non-uniform movement	The study of non-uniform movement requires the introduction of **average velocity** (introduced as total distance divided by total time), as contrasted with **instantaneous velocity** (introduced at this level as the quasi-constant velocity over a very short time interval). **Velocity** Symbol: *v* Unit: m/s Definition: $v = \Delta x/\Delta t$	Concrete examples, e.g. composite journeys.

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K3. Accelerated movement.	If velocity changes uniformly with time, the **acceleration** is said to be **constant** or **uniform**, and is introduced as the velocity change every second. In this case, the value of the average velocity is given by the **mean** of the initial and final velocities. The v/t graph is a straight line. The acceleration of free fall is approximately uniform, of value 10 m.s^{-2} on earth. **Acceleration** Symbol: *a* Unit: m/s^2 Definition: $a = \Delta v/\Delta t$ **Average Speed** Symbol: $<v>$ Definition: $<v>$ = *Total distance/Total time* For uniformly accelerated movement: $<v> = ½(v_{initial} + v_{final})$ "*g*" ≈ 10 m/s^2 *at the surface of the Earth.* **Time: 11 periods (K)**	Experimental measurement of free fall acceleration for different masses. Qualitative effect of air friction. Graphical methods based on the v/t graph. A fast group might examine the x/t graph also. Real-world links include effects of deceleration and reaction time on braking distance.
Section E. Electricity. **E1. Electrostatics.** **1.1 Electric charge.**	**Charges** are of two kinds called ***positive*** and ***negative***. These charges exert forces on each other. Charges of the same kind repel one another; those of different kinds attract one another.	Experiments on charging by rubbing. Static discharge on getting out of a car. The Faraday cage. The gold leaf (or other) electroscope.
1.2 Model of the atom.	The **atom** consists of positively and negatively charged particles, normally in equal numbers. It is possible to remove some negatively charged particles (**electrons**) from the atom; the result of this is that the body from which they are removed is left **positively charged**, and the body which received them becomes **negatively charged**.	

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1.3 Measurement and conservation of electric charge.	The charge a body possesses may be measured by the **number of excess electrons**, but each of these has a very small charge; the practical unit of charge is that of a large (but specific) number of electrons. Charge cannot be created or destroyed The charge of the electron is known as the **elementary charge**.	Using different cloths (and paper etc.) to charge the same plastic material. The gold-leaf electroscope and the charge-meter (d.c. amplifier).
1.4 Separation of charge.	The influence of a charged body can cause the **separation of charges** in an otherwise uncharged conductor. **Charge** Symbol: Q Unit: Coulomb C	
E2. Electrodynamics. **2.1 Current.**	Electrons can move through certain materials (which are called ***conductors***), notably metals, but not through others (which are called ***insulators***). This movement constitutes an electric **current**, introduced as the **amount of charge passing through a conductor each second**. Electric charge can carry and deliver energy. **Current** Symbol: I Unit: Ampère A Definition: $I = \Delta Q/\Delta t$	Mechanical models.
2.2 Voltage.	**Voltage** is introduced as the **energy delivered by each Coulomb** to a device (e.g. to a bulb or motor).	Complete experimental treatment leading to the rules of behaviour of voltage and current in circuits, based on a suitable model.

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	Voltage Symbol: U Unit: Volt V=J/C=W/A Definition: $U = \Delta E/\Delta Q$ **Electrical Power** $P = U\cdot I$	Links with mechanical power and energy. Power in fluorescent and incandescent bulbs.
2.3 Electric circuits.	**Conservation of charge** implies that the current in a series circuit has the same value at all points, while in a parallel circuit the total current is the sum of the currents in the different branches. Current is measured with an ammeter connected in series with the circuit. The total voltage across a series circuit is the sum of the individual voltages, and the voltage across a parallel circuit is the same as the individual voltages across its elements. Voltage is measured with a voltmeter, connected in parallel with a circuit element. **Series Circuit:** $I_1=I_2=I_3=.....$ $U=U_1+U_2+U_3+......$ **Parallel Circuit:** $I=I_1+I_2+I_3+.....$ $U_1=U_2=U_3=.......$ **Time: 10 periods (E)**	Traffic or river flow rate. Practical work with simple circuits. Water analogue. Displacement of ions during electrolysis. The immersion heater, the electric motor lifting loads. (Link with efficiency, M 2.5, and with gravity force.)

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Section N. Nuclear Physics **N1. Origin of radiation.**	The **nucleus** of the atom is a compact entity consisting of **protons** and **neutrons**. The nuclei of some atoms can spontaneously change their constitution, and in doing so emit so-called **radiation**.	Demonstrations with the Geiger-Müller tube. Background: cosmic rays.
N2. Basic notions.	Examination of this radiation's penetrating power suggest that three different types of radiation exist. These are known as α –, β – and γ – rays, in increasing order of penetrating power. These rays are capable of disrupting the cells of the body and hence of causing illness.	Experiments on penetrating power.
N3. Activity; half-life.	An atom which has changed its constitution as described above is said to have **decayed**. The **activity** of a sample may be introduced as the number of decays occurring each second. In a given time, characteristic of the element concerned, half of the atoms (on average) will decay, no matter how many atoms there were to start with. This time is the **half-life**. **Activity** Symbol: A Unit: Becquerel Bq = s^{-1}	Ionization chamber: the A/t curve.
N4. Stimulated decay.	Some nuclei which do not naturally decay may be induced to do so. One important way to bring this about is by bombardment with neutrons.	
N5. Chain reaction.	Such bombardment may lead to the nucleus splitting, with the emission of more neutrons. This can result in a **chain reaction**, in the course of which large quantities of energy are released. **Time: 5 periods (N)** **Total time estimate, year 4: 6+8+6+11+10+5 periods = 46 periods.**	An examination of the benefits, drawbacks and risks of various forms of energy production.

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Section M. Mechanics. **M4. Dynamics.** **4.1 Equilibrium.**	**Part 2. 5th Year Programme.** **Equilibrium** exists in the absence of force. Two equal and opposite forces annul mutually, and also therefore result in equilibrium.	
4.2 Movement of a body in equilibrium.	A body in equilibrium moves with a constant speed in a straight line. $\Sigma F = 0 \iff v = constant$ $\Sigma F = m \cdot a$ *Unit relationship:* N = kg·m/s^2	Airtrack and rail experiments.
4.3 Movement of a body under a steady force.	A body moving under the influence of a steady resultant force moves with **constant acceleration**, whose magnitude is directly proportional to the force and inversely proportional to the mass. The **Newton** is defined by this relationship. **Mass** is to be distinguished from **weight**: the latter is a variable force, and is normally identical with the gravitational force, whereas the former is a property of the body describing the difficulty in accelerating it.	Crumple zones and seat belts in cars, action of crash helmets. Experimental work with pulse timers and electronic or video timing methods
4.4 Free fall under gravity.	The **acceleration due to gravity** is approximately 10 m.s^{-2} on earth. Relationship with M 1.1.	
4.5 Mutual nature of force.	No force exists alone; there exists only **mutual force between two bodies**. If A exerts a force on B, then B necessarily exerts an equal and opposite force on A.	
4.6 Kinetic Energy.	The work done by the force accelerating a body in the absence of friction is converted into the body's **kinetic energy.** **Kinetic Energy** $E_k = \frac{1}{2} m \cdot v^2$	

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Section E. Electricity. **E3. Resistance.** **3.1 Basic notions.**	**Time: 12 periods (M4)** Different materials offer different **resistances** to the passage of electric current. High resistances tend to reduce current, or to require a large expenditure of energy for the passage of charge (engendering high voltages). **Resistance** Symbol: R Unit: Ohm Ω Definition: $R = U/I$	Experiments with different wires, lengths, diameters.... Conduction by a red-hot glass rod. Link with kinetic theory.
3.2 Ohmic resistors. **3.3 Resistance in circuits.**	The resistance of a **conductor** at constant temperature has a constant value. The combined resistance of series resistances is equal to their sum, whereas in a parallel circuit, adding more resistance elements reduces the effective resistance. **Series Circuit:** $R = R_1 + R_2 + R_3 + ...$ **Parallel Circuit:** $1/R = 1/R_1 + 1/R_2 + 1/R_3 + ...$	Domestic installations; earthing, safety, overheating of coiled cables. Power transmission, and the use of transformers to improve efficiency.

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3.4 Factors determining resistance.	The resistance of a conductor depends on its **length**, its **cross-sectional area** and the **resistivity** of the material of which it is made. **Resistivity** Symbol: ρ Unit: Ω·m, Ω·mm²/m Definition: $R = \rho \cdot l/A$	Resistive putty.
3.5 Non-ohmic resistance.	Some circuit elements, e.g. the light dependent resistor, the diode, the thermistor, have resistances which are **not constant** for given physical dimensions, but which vary with other physical conditions (light intensity, current, temperature). A qualitative study only is required.	The transistor, logic gate or op-amp as a switch may be introduced. The rectifier.
3.6 Circuit applications of non-ohmic components.	The components mentioned above may be used for rectification, or for producing a voltage varying with physical conditions which can be used for switching purposes. Some applications should be examined, for example, frost warning, automatic switching of lights etc. **Time: 12 periods (E3)**	
E4. Magnetism and electromagnetism. **4.1 Permanent magnets.**	Objects which attract certain materials placed in their vicinity (e.g. Iron, Cobalt, Nickel...) are called **magnets**. There exists a **magnetic field** in the region in which the attraction is effective. Those parts of a magnet exerting the strongest attraction are called the **poles** of the magnet; they always appear in pairs, and experiment shows them to be of two kinds. Two similar poles repel one another, and two dissimilar poles attract one another. Hence a magnet suspended in the field of another will adopt a preferential orientation. Such behaviour is also observed in a magnet suspended above the earth, which may therefore be considered to be surrounded by a magnetic field: one pole (the *north-seeking* pole) will point roughly northwards, and the magnet may thus be used as a compass.	Revision of Integrated Science work. Identification of ferromagnetic materials. Broken magnets. Demagnetization by heating. Model with a test-tube full of Iron filings.

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4.2 Magnetic field of a current.	A straight current-carrying wire and a coil both produce magnetic fields. A practical rule should be taught to determine the directions of these fields. The field of a coil is increased in strength by the presence of a ferrous core.	Oersted's experiment. Deflection of a beam of charged particles. Current balance.
4.3 Electromagnetic force.	A current-carrying conductor placed in a magnetic field may experience a force. This make it possible to construct electric **motors**.	
4.4 Electromagnetic induction.	A conductor moved in a magnetic field may produce a voltage. This makes it possible to construct **dynamos**. **Time: 6 periods (E4)**	
Section H. Heat and energy. **H1. Heat.**	**Heat** is a form of energy (and therefore measured in joules), which is associated with the kinetic energy of the molecules of a body. **Temperature** is measured in degrees with a thermometer, and is also associated with molecular movement. Energy moves spontaneously (as heat) from regions of high to regions of low temperature. Temperature *changes* are measured in **Kelvins** (1 K = 1°C). **Heat Energy** Symbol: *Q* Unit: Joule J **Temperature** Symbol: T, θ Unit: Degrees Celsius °C Kelvins K *Note: The two units are the same when measuring temperature differences.*	Warming experiments with water heated by electrical and by mechanical means. Solar panels, Trombé walls. Energy efficiency and environmental protection; advantages and disadvantages of the use of fossil fuels.

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H2. Specific heat capacity.	The **temperature change** of a body is proportional to the energy supplied to it. The **specific heat capacity** of a substance may be introduced as the energy required to increase the temperature of 1 kg of a given substance by 1K.	
H3. Latent heat.	Change of state (melting, evaporating) requires input of energy which does not produce a change of temperature. This energy is called **latent heat**. The **specific latent heat** may be introduced as the energy required to change the state of 1 kg of a substance. **Specific Heat Capacity** Symbol: c Unit: J/kg·K Definition: $Q = m \cdot c \cdot \Delta\theta$ **Specific Latent Heat** Symbol: L Unit: J/kg Definition: $Q = m \cdot L$	
H4. Molecular theory.	The calorific phenomena described above may be explained with the aid of a **molecular model**. **Time: 8 periods (H)**	
Resumé of energy.	The pupil should by now have met the following forms of energy, and should be able to discuss energy conversions involving them. In cases of energy forms marked with an asterisk (*), quantitative work should be possible: Gravitation potential energy*, chemical potential energy, heat energy*, kinetic energy*, electrical energy*, nuclear energy. Various examples of energy changes should be examined.	

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Section V. Vibrations and waves. **V1. Basic notions.**	Movements are frequently observed which are **periodic** in character. Such movements are called **oscillations** or **vibrations**. The **period** is the time to complete one cycle of movement, the **frequency** is the number of cycles or vibrations per second, and the **amplitude** is the maximum displacement from the equilibrium position.	Heartbeats, rhythms of diurnal and annual movement of earth and other heavenly bodies, movement of strings in musical instruments, rotation of a turntable.
V2. Resonance.	It is possible (and common) for one oscillator's action to provoke a response in another oscillator which is **linked** to it in some way. This response can be very large if the natural frequencies of the two oscillators are the same, and this phenomenon is known as **resonance**. Examples might include pushing a child on a swing, vibration of bus windows, etc. No formal or quantitative study should be undertaken.	Pushing a child on a swing, linked pendula etc.
V3. Waves. **3.1 Basic notions.**	A periodic disturbance may **propagate** in an elastic medium, giving rise to a **wave** whose form repeats itself at regular time intervals and regular distance intervals. The **wavelength** λ is the distance between two corresponding points on a wave. The wave **velocity** may also be defined. For sound, this is about 340 m/s. **Frequency** Symbol: f Unit: Hertz Hz = s^{-1} Definition: $f = 1/T$ *where* T = *period* **Wavelength** Symbol: λ Unit: m **Velocity of propagation** Symbol: v, c Unit: m/s $v = f \cdot \lambda$	"Echelle de Perroquet", ripple tank demonstrations. Measurement of the speed of sound.

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3.2 Diffraction.	Waves can pass around an obstacle or spread out after passing through a gap; this behaviour is called **diffraction**, and its extent depends on the wavelength and on the size of the gap or obstacle. This has practical consequences for radio reception. **Time: 9 periods (V)** **Total time estimate, year 5: 12+12+6+8+9 periods = 47 periods.**	Demonstrations in the ripple tank and with microwaves.