**BTEC Level 3 Nationals in Applied Science**

**Additional Guidance**

**Unit 5 – Section C – Thermal physics, materials and fluids**

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| **Essential Content** | **Additional Guidance** |

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| **C1 Thermal physics in domestic and industrial applications** | Learners should: |
| * Be able to use the following quantities and units: |  |
| * power, watt (W), kilowatt (kW), megawatt (MW), gigawatt (GW) | * know that the unit of energy is the joule (J) and that power is the energy transferred each second i.e. watts = joules/time (J/s) * be able to convert between these units and multiples of units, e.g. know that 1 GW = 109 W |
| * convert °C to K | * be able to convert between these units |
| * pressure (Pascals (Pa), Newton per metre squared (Nm-2)) | * know that Force is measured in newtons (N) * understand that pressure is force per unit of area * be able to substitute values for any two of pressure, *P* or force, *F* or area, *A* into the equation *P = F/A* and calculate a value for the other term * be able to re-arrange the equation |
| * Know the following definitions: |  |
| * work done as energy transferred | * understand that whenever work is done energy is transferred from one form to another. The amount of work done in J = the amount of energy transferred in J |
| * work done as force × distance moved in direction of force (*W* = *F* × ∆*s*) | * be able to substitute values for any two of work done, *W* or force, *F* or distance moved in the direction of the force, ∆*s* into the equation (*W* = *F* × ∆*s*) and calculate a value for the other term * be able to re-arrange the equation |
| * work done by a gas as pressure × change in volume of gas (*W* = *p* × ∆*V*) | * be able to substitute values for any two of work done, *W* or pressure of gas, *p* or change in volume of the gas, ∆*V* into the equation (*W* = *p* × ∆*V*) and calculate a value for the other term * be able to re-arrange the equation * know that this equation can be combined with the equation above it to give the unit for pressure as Nm-2, e.g. *F* × ∆*s* = *p* × ∆*V* |
| * Be able to calculate efficiency using the relationships: |  |
| * efficiency = work output / energy input | * be able to substitute values for any two of efficiency or work (or energy) output or energy (or work) input and calculate a value for the other term * be able to re-arrange the equation |
| * for heat engines:   efficiency = 1 - (Q*out / Qin)* | * know that a heat engine is any device that converts heat or thermal energy into useful work or other useful forms of energy, e.g. burning coal in a power station to produce electrical energy * be able to substitute values for any two of efficiency or work (or energy or power) output, *Qout* or energy (or work or power) input, *Qin* and calculate a value for the other term * be able to re-arrange the equation |
| * maximum theoretical efficiency = 1 - (T*C / TH)* | * be able to substitute values for any two of maximum theoretical efficiency or temperature in kelvins of the output (exhaust or cold reservoir), *TC* or temperature in kelvins of the heat engine (or hot reservoir), *TH* and calculate a value for the other term * be able to re-arrange the equation |
| * Understand the following concepts: |  |
| * law of conservation of energy | * know the definition of the first law of thermodynamics in words as, the heat energy supplied to a system is equal to the increase in the internal energy of the system plus the work done by the system on its surroundings, well as the equation Q = ΔU + ΔW |
| * ideal gas equation *pV* = *NkT* | * know that *pV = NkT* applies to molecules of a gas and N is the number of molecules and k is a constant called the Boltzmann constant * be able to perform appropriate calculations remembering that *T* is in kelvins * understand that the ideal gas equation *pV = nRT* applies to moles of a gas * be able to use the ideal gas equation, where R is the Universal Gas constant and n is the number of moles of the gas * understand that the formula can be rearranged into the form *pV/T =nR* (a constant) and therefore use the equation *p1 V1* / *T*1 = *p2 V2* / *T*2 in calculation |
| * internal energy (*U*), first law of thermodynamics (*Q* = ∆*U* + *W*) | * understand that internal energy is the sum of, on a molecular level, the kinetic (energy of vibration/ random motion of particles) and potential energy (energy in bonds) of the particles * understand the symbols in the equation:   + Q as thermal (heat) energy added to the system   + ∆U as the change in internal energy   + + W as the work done on the system * understand the significance of a + or a – before each term, for example -W means that work is done by the system and +W is the done on the system |
| * isothermal and adiabatic processes | Isothermal processes:   * know and understand situations, to include for example: bicycle and car pumps, steam, petrol and diesel engines, refrigerators and air conditioners where work is done on or by a gas at constant temperature and the effect on the gas. In an isothermal process thermal energy can be added or released in order to keep the temperature constant (i.e. ∆U = 0 as internal energy is proportional to temperature in kelvins). In an isothermal process the transformation is usually slow   Adiabatic processes:   * know and understand situations, to include for example: bicycle and car pumps, steam, petrol and diesel engines, refrigerators and air conditioners, where work is done on or by a gas without an input/output of thermal energy, and the effect on the gas. In an adiabatic process no thermal energy is added or released from the system (i.e. Q = 0) and the transformation is usually fast. In an adiabatic process all the change in internal energy is in the form of work done on or by the system in the process |
| * idealised engine cycles | * know and understand examples of the idealised engine cycles, to include the Carnot cycle and Otto Cycle * understand the graphical representation of the idealised engine cycle |
| * second law of thermodynamics | * know the second law of thermodynamics in terms of entropy and the direction in which heat energy moves * understand it as a limiting factor in the efficiency of heat engines, i.e. know that it is not possible to convert thermal energy continuously into other useful forms of energy or work without at the same time transferring some of the thermal energy from a warmer body (heat engine) to a colder body (or surroundings) |
| * heat engines, refrigerators and heat pumps | * understand the graphical representation of heat pump cycle * understand the differences and similarities between the action of a heat engine, to include the Stirling engine, and a heat pump * understand the action of a refrigerator as a reverse heat engine/pump * know that under normal circumstances, heat only flows from high temperatures to low temperatures. In order to move heat from a low temperature environment to a high temperature environment, work needs to be done (or energy needs to be transferred) |
| * maximum theoretical coefficient of performance (COP) | * understand that the COP for a heat pump or engine is the ratio of the energy transferred for heating to the input energy used in the process * know that higher the COPs equate to lower operating costs * know that COP = Q/W where Q is the thermal energy supplied or removed from the system and W is the work done on or by the system  or: COP = Thot/ ( Thot – Tcold) |
| * Understand the changes of state of substances used in domestic and industrial processes: |  |
| * transfer of energy producing temperature change or changes of state, thermal capacity, thermal equilibrium | * understand the difference between the specific heat capacity of a substance and the thermal (heat) capacity of an object or system and the units of measurement of each |
| * specific heat capacity from (*Q* = *mc*∆*T*) | * understand how to experimentally determine the SHC of a solid, e.g. a metal such as aluminium and a liquid such as water * be able to substitute values for any three of thermal energy supplied/given out, *Q* or mass, *m* or specific heat capacity, c or temperature change, ∆*T* into the equation (*Q* = *mc*∆*T* ) and calculate a value for the remaining term * be able to re-arrange the equation |
| * specific latent heat from (*Q* = *mL*), fusion, vapourisation, condensation | * understand how to experimentally determine the SLH of fusion or vapourisation, of water and other common substances * understand fusion, vaporisation and condensation on a molecular level in terms of the arrangement of particles, the forces between the particles and the distance of separation of particles in solids, liquids and gases * be able to substitute values for any two of thermal energy supplied/given out, *Q* or mass, *m* or specific latent heat, *L* into the equation (*Q* = *mL* ) and calculate a value for the remaining term * be able to re-arrange the equation |
| **C2 Materials in domestic and industrial applications** |  |
| * Understand the following concepts and apply them in domestic and industrial applications: |  |
| * elasticity | * understand the properties of an elastic material in the elastic region of a stress/strain or Force /extension graph |
| * stress-strain curves | * be able to interpret curves and be able to identify key points and regions including: the limit of proportionality, the elastic limit, the yield point and breaking point * be able to recognise curves for different materials, to include: iron, copper, nylon, glass, and rubber/elastic bands * understand the molecular behaviour of the material in the Hooke’s law region, to include: the limit of proportionality, the elastic limit, the yield strength/point and breaking/fracture point |
| * elastic limit | * know that the elastic limit can be referred to as the point beyond which the material will not return to its original shape. The elastic limit is just beyond the limit of the Hooke’s law region (region of proportionality) for material |
| * strength | * understand the difference between the strength of a material and how strong it is |
| * yield point | * understand what happens at the molecular level at the yield point, in terms of slip planes and the way the material behaves at the yield point |
| * plastic deformation | * understand the properties of plastic deformation in the region beyond the yield point of a stress/strain or Force /extension graph * understand how metals, to include: copper and steel, can be deformed plastically |
| * creep | * understand the term and be able to explain how factors such as temperature change, changes of stress on a material cause the material to deform over time |
| * fatigue | * know the factors that lead to fatigue in metallic and non-metallic materials * understand the steps that can be taken to reduce the effect * know that fatigue is the progressive and localised structural damage that occurs when a material is subjected to cyclic loading /repeated loading and unloading * know that the loads involved are often much smaller than those needed to cause failure in the material |
| * ductility | * know materials that are ductile, to include: gold, silver, iron, aluminium, tin and lead and understand why they are ductile * know that practically, a ductile material is a material that can easily be stretched into a wire when pulled |
| * brittleness | * know materials that are brittle, to include: cast iron and glass and ceramic materials, and understand why they are brittle * know that a material that fractures with no plastic deformation is a brittle material |
| * malleability | * know that a malleable material is one in which a thin sheet can be easily formed by hammering or rolling, i.e. the material has the ability to deform under compressive stress * know materials that are malleable, to include: most metals such as gold, silver, copper ,tin, iron and aluminium, and understand why they are malleable |
| * elastic hysteresis | * know materials that demonstrate this property to include: rubber and elastic bands and explain why they have this property in molecular terms * know that the area between the curves in the hysteresis loop is equal to the energy lost in stretching the material. This energy loss results in a rise in temperature of the material * know that for a complete cycle the increase in thermal/heat energy of the material is equal to the area of the hysteresis loop |
| * Be able to use the following quantities and units: |  |
| * density kgm-3 | * know that the density of a material is the ratio of its mass to its volume |
| * tensile/compressive stress (Newton per metre squared (Nm-2)) | * know that the pascal (Pa) is equivalent to the Newton per metre squared (Nm-2) and so be able to use Pascal (Pa) as a unit of tensile/compressive stress |
| * tensile/compressive strain (no units) | * know that strain is a ratio is a ratio of two distances and so has no units |
| * Young’s modulus (Newton per metre squared (Nm-2)) | * know that Young’s modulus can be only calculated from the gradient in the Hooke’s Law region/ region of proportionality of a stress/strain graph * know how the value can be experimentally determined |
| * Understand the following definitions: |  |
| * density *p = m / v* | * be able to convert between units used to measure density, for example: gm to kg and cm3 to m3 * be able to substitute values for any two of density, *ρ* or mass, *m* or volume, *V* into the equation *ρ = m / v* and calculate a value for the remaining term * be able to re-arrange the equation * be able to describe how to measure the density of solids and liquids |
| * tensile/compressive stress = *F / A* | * know and use the terms compressive and tensile to describe the stress placed on materials * understand the direction in which tensile/compressive stress is applied to produce a tensile/compressive strain * be able to substitute values for any two of tensile/compressive stress or force (load), *F* or (cross-sectional) area, *A* into the equation tensile/compressive stress = *F / A* and calculate a value for the remaining term * be able to re-arrange the equation |
| * tensile/compressive strain = ∆*x / L* | * understand that strain is a dimensionless quantity as it is the ratio of two distances * understand that tensile/compressive strain is linear because of the direction of the stress applied * be able to substitute values for any two of tensile/compressive strain or extension (stretch) of the material, ∆*x* or original length of material, *L* into the equation:   tensile/compressive strain = ∆*x / L* and calculate a value for the remaining term   * be able to re-arrange the equation |
| * Young’s modulus *E* = stress / strain | * be able to use the equations for the terms:   + *F / A* for stress   + *∆x / L* for strain * be able to use the equation *E = F.L/ A.∆x* * be able to determine Young’s modulus, *E* from the gradient of a stress/strain curve |
| * Hooke’s law *F* = *k*∆*x* | * be able to substitute values for any two of force (load), *F* or stiffness constant ( constant of proportionality), *k* or extension (stretch) of the material, ∆*x* into the equation *F* = *k*∆*x* and calculate a value for the remaining term * be able to re-arrange the equation * know that in the region of proportionality the stiffness constant, *k* determines the slope or gradient of a (force) load/extension graph |
| * work done in stretching/compressing a wire/spring   = ½ *F*∆*x* = ½ *k(*∆*x*)2 | * be able to substitute values for any two of work done, W or force (load), *F* or extension (stretch) of the material, ∆*x* into the equation *W* = *½ F*∆*x* and calculate a value for the remaining term * be able to re-arrange the equation * be able to substitute values for any two of work done, W or stiffness constant ( constant of proportionality), *k* or extension (stretch) of the material, ∆*x* into the equation *W* = *½ k(*∆*x)2* and calculate a value for the remaining term * be able to re-arrange the equation * be able to calculate work done in stretching a wire/spring by determining the area below a load/extension graph |
| **C3 Fluids in motion** |  |
| * Understand the following concepts and apply them in industrial and domestic situations: |  |
| * fluid flow patterns, streamline and turbulent flow | * know that a smooth or steady flow is also referred to as laminar flow the streamlines are smooth * know that in turbulent flow streamlines cross and mix * know that a streamline shows the direction of flow of a fluid * know that as fluid velocity/speed increases streamlines move closer together * know that as streamlines move closer together internal fluid pressure decreases * be able to draw types of flow or identify types of flow * know that the term ‘fluid’ includes both liquids and gases |
| * viscosity | * know that viscosity is the quantity that describes a fluid’s resistance to flow * understand the factors, to include: temperature, molecular structure and pressure that affect the viscosity of a fluid * be able to recognise differences in viscosity from streamline diagrams * be able to compare viscosities experimentally, e.g. in terms of time taken for a small object to fall through a fluid or the time taken for a fluid to flow through a small hole in a container * understand the effect of temperature on the viscosity of a fluid   *Learners do not need to know how to find the viscosity of a fluid using Stokes law* |
| * viscous drag | * understand that viscous drag is the resistance to the flow of a fluid * know that viscous drag increases with the speed of flow * understand the difference between viscous drag in streamline and turbulent flow |
| * mass of fluid flow per second for all points along a pipe or stream tube is constant | * understand why some liquids are incompressible * know that the volume flow rate, i.e. mass of fluid flow per second is constant for liquids that are incompressible |
| * non-Newtonian fluid flow | * understand the features of non-Newtonian fluids, to include: Thixotropic, Rheopectic, Shear Thinning and Shear Thickening materials * understand the behaviour of non-Newtonian fluids, to include: paints, honey, ketchup, toothpaste, cream, Oobleck * understand the effects of applied stress to non-Newtonian fluids |
| * rate of fluid flow and pressure | * know that fluid flow is related to the area of cross section of a pipe, i.e. with an incompressible fluid, the narrower the pipe the greater the flow rate * know that the pressure of the fluid is related to rate of flow in streamline (laminar) flow, i.e. the faster the flow rate the lower the (internal) pressure of the fluid |
| * Bernoulli’s principle | * understand the Bernoulli’s principle or the Bernoulli effect as:   + when an incompressible, smoothly flowing fluid gains speed, internal pressure of the fluid decreases and when the fluid’s speed decreases, internal pressure increases   *Learners do not need to know or use the equation relating to the principle* |