Energy

Energy analysis determines whether some processes are possible. It involves calculating the amounts of energy stored in different places and in different ways. An energy analysis is one of many ways of examining physical processes. If we want to explain how a microphone works, there is lots to discuss but little benefit from mentioning energy. However, if we want to know how much fuel is needed to lift a satellite into space, then we must perform calculations based on energy.

You will calculate energy as it is stored: thermally, gravitationally, elastically, as kinetic energy, and as nuclear energy. Whilst the energy stored in these different ways may differ before and after a physical change, the **total** energy is the same.

30 Thermal Energy

Hot objects (or substances) store energy thermally.

The energy is associated with the random, thermal motion of a substance's atoms or molecules. The physical processes of conduction, convection and radiation can result in increases or decreases of a thermal energy store.

If two objects at different temperatures are in contact with each other, then energy is exchanged between their particles. After some time the thermal energy store of the hotter object will have decreased (and its temperature will have decreased) and the thermal energy of the cooler object will have increased (and its temperature will have increased). This thermal process is called conduction. When the objects reach the same temperature, we say they are in thermal equilibrium and the thermal energy of each will then remain constant.

Hot objects emit electromagnetic radiation. After a period of time, the thermal energy store associated with a hot object will have decreased (and the temperature of the hot object will be lower than it was).

Thermal energy is measure in joules (J).

Heating involves the transfer of thermal energy from a warmer (higher temperature) object to a cooler (lower temperature) object.

The amount of thermal energy required to increase the temperature of an object (of a certain substance) by $1\ ^{\circ}$C is called the heat capacity of that object. The heat capacity per kilogram is called the specific heat capacity (of that substance). Therefore,

change in thermal energy $=$ mass $\times$ specific heat capacity $\times$ change in temp.

$$\Delta Q = mc\Delta T$$

Specific heat capacity is measured in J/(kg °C) or the equivalent unit J/(kg K).

The specific heat capacity of pure water is 4 200 J/(kg °C).

30.1 Work out the missing measurements from the following table, where each row is a separate question.

ΔQ	m	c (J/(kg °C))	ΔT (°C)
(a)	2.50 kg	800	30.0
5 625 J	(b)	750	15.0
34.125 kJ	250 g	(c)	65.0
69.0 kJ	1.20 kg	250	(d)
(e)	2.0 kg	4 200	10
90 000 J	(f)	450	10
2.1×10^{5} J	10 kg	(g)	5.0
8 000 J	1.0 kg	400	(h)
(i)	0.50 kg	4 200	40
10 500 J	(j)	2 100	20
67 500 J	5.0 kg	(k)	30
2.5×10^{4} J	0.50 kg	1 000	(l)

30.2 What is the change in thermal energy of 1.00 kg of water that is raised from 20.0 °C to its boiling point? (Assume the system is well insulated.)

30.3 How much energy is required to raise the temperature of a 200 g block of ice from -10.0 °C to 0.0 °C? (The specific heat capacity of ice is $2\,100$ J/(kg °C). Assume the system is well insulated).

30.4 The specific heat capacity of ice is $2\,100$ J/(kg K). A 1.8 kg block of ice, removed from a freezer at a temperature of -18 °C, is placed in a fridge which has a temperature of 0.0 °C. After a few hours, the ice has warmed up to the fridge temperature. What is the change in the stored thermal energy of the block?

30.5 The specific heat capacity of air is 1000 J/(kg K).

(a) How much energy would be needed to raise the temperature of the air in a room by 5.0 °C, if the room measures 4.0 m $\times$ 4.0 m $\times$ 3.0 m? (Take the density of air $= 1.0$ kg/m^3). Assume that the room has no furniture and that the walls gain no thermal energy.

(b) How long would a 1.0 kW convection heater take to heat the air?

30.6 A carpet cleaning machine holds 40 litres of water. It is filled with water at 15 °C and the water is then heated by a 3.0 kW element to a temperature of 70 °C.

(a) How much energy is added to the water? [Mass of 1.0 litre $=$ 1.0 kg; s.h.c. $= 4\,200$ J/(kg K)]

(b) Assuming there is no change in the thermal energy store in the machine or air, how long does it take to heat the water?

30.7 An energy of $75\,600$ J must be supplied to raise the temperature of a 2.0 kg block of ice, initially at -18 °C, to its melting point. Calculate the specific heat capacity of ice suggested by these figures.

30.8 Calculate the specific heat capacity of a 3.0 kg piece of metal which experiences a temperature rise of 25 °C when it is heated at a rate of 60 W for 10 minutes, if a total of $3\,000$ J is lost to the surroundings during this process.

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30.9 Assuming the system is well insulated, what temperature would 490 g of water reach, starting at 15 °C, if a 60 W heater heated it for 20 minutes? [Specific heat capacity of water = 4 200 J/(kg K)]

Additional Thermal Energy Questions

30.10 Calculate the thermal energy needed to raise the temperature of a 2.5 kg block of ice to its melting point, if it is taken from a freezer at −18 °C. [$c_{\text{ice}} = 2.1$ kJ/(kg K)]

30.11 The specific heat capacity of iron is 440 J/(kg K). How much thermal energy is gained when the temperature of 800 g of iron is raised by 120 °C?

30.12 Copper has a specific heat capacity of 390 J/(kg K). A 20 g piece of copper at 1 050 °C is dropped into a very large tank of water which is at 15 °C. What is the change in the thermal energy of the water when the copper has cooled to the temperature of the water?

30.13 When 30 g of gold is warmed by 50 °C, the change in its thermal energy store is 260 J. From these figures calculate the specific heat capacity of gold.

30.14 10 kg of water at 40 °C is mixed with 10 kg of water at 20 °C in a bath. Assuming that the total energy stored in the water does not change (none is lost to the surroundings), what will be the final temperature of the water? Hint: imagine energy leaving the "store" of the hotter water to increase the energy "stored" in the colder water, until the temperatures are equal.

30.15 A 1.50 kg lump of aluminium [$c = 910$ J/(kg °C)] at 100 °C is dropped into a beaker containing 1.00 kg of water at 20.0 °C. Assuming the system is well insulated, what temperature will the aluminium and water be when in thermal equilibrium?

30.16 Babies must be bathed at exactly 37 °C. A bath contains 10 kg of water at 15 °C. How much water at 50 °C needs to be added to make the temperature correct for bathing a baby? Hint: in your working, take the mass of hot water to be m, and write down equations which later enable you to work out the value of m.