Thermal Physics

Name _____ Date _____

By the end of this topic I can…

- use the Celsius and Kelvin scales, and describe the kinetic model of solids, liquids and gases
- use specific latent heat and specific heat capacity
- define internal energy and explain how it changes during heating and changes of state
- use the first law of thermodynamics $\Delta U = Q + W$ and $W = p\Delta V$
- describe thermal equilibrium, absolute zero and how thermometers work

Thermal basics

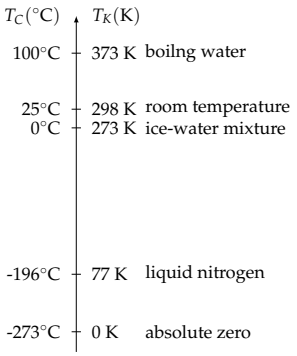
Temperature scales

• **Celsius scale** (unit °C): 0 °C is the temperature of an _____; 100 °C is the temperature of _____

• **Kelvin scale** (unit K): 0 K is _____, the lowest temperature possible

• conversion:

• a change of 1 °C equals a change of _____



Some temperatures on the two scales.

Kinetic theory of matter

The **kinetic theory of matter** explains *macroscopic* properties (density, compressibility, fluidity) from the *microscopic* behaviour of molecules.

• _____: molecules close together, tightly bonded, _____ about fixed positions

• _____: molecules quite close, vibrate but with some freedom to _____

• _____: molecules widely separated, free from neighbours, move _____

Specific latent heat

Changing state at constant temperature needs energy: the **latent heat**. It depends on the mass:



_____ L is the thermal energy required to change the _____ of _____ of a substance with _____.

- unit: $[L] =$ _____
- L depends only on the type of substance; for melting it is the specific latent heat of _____, for boiling of _____, and L_{vap} is _____ than L_{fus}

Example 22.1 A 3.0 kW kettle holds 0.50 kg of water already at its boiling point. Neglecting heat losses, how long does it take to boil dry? ($L = 2.26 \times 10^6$ J kg^{-1})

Example 22.2 A student measures L for ice with an electric heater, but the insulation is imperfect. Two runs at different powers give: test 1: 60 W, 3.0 min, 40.4 g melted; test 2: 90 W, 3.0 min, 56.6 g melted. Find L.

Question 22.1 In an experiment to find L for ice, ice at 0 °C is melted twice. Heater off: 10.0 min, 14.3 g melted. Heater on: 21 000 J supplied in 5.0 min, 70.0 g melted. (a) Why are two sets of readings taken? (b) Find L.

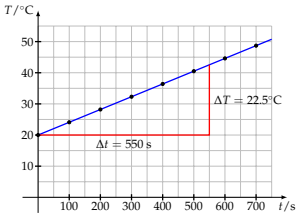
Specific heat capacity

Heating a substance (with no change of state) raises its temperature:

_____ c is the thermal energy required
_____ to raise the temperature by _____ (1 K).

• unit: $[c] =$ _____; c does not depend on the size or shape of the sample

Example 22.3 30 g of ice at −20 °C is added to 270 g of water at 80 °C. No energy is lost. Find the final temperature. ($c_{\text{water}} = 4200$, $c_{\text{ice}} = 2100$ J kg^{-1} K^{-1}; $L_{\text{ice}} = 3.3 \times 10^5$ J kg^{-1})



Example 22.4 A 1.00 kg aluminium block is heated by a heater with current 4.2 A and p.d. 12 V. The graph shows the temperature rising. Find the specific heat capacity of aluminium.

Question 22.2 A mixture is 5% silver and 95% gold by mass. Molten gold is mixed with silver at 20 °C so that the final mixture is at the melting point of gold (1340 K). Find the initial temperature of the gold. Silver: melting point 1240 K, $c = 235\ \text{J kg}^{-1}\ \text{K}^{-1}$, $L = 105\ \text{kJ kg}^{-1}$. Gold: $c = 129\ \text{J kg}^{-1}\ \text{K}^{-1}$ (solid or liquid).

Internal energy

_____ is the sum of the
_____ of the molecules and the
_____ the molecules:

It is a **state function**: it depends only on the current state, not on how it got there.

• **kinetic** part: from random motion only (not the motion of the whole system); the mean K.E. of molecules is _____: $E_k \propto T$

• **potential** part: from forces *within* the system (not external fields); greater intermolecular separation means greater E_p, and _____ also

increases E_p

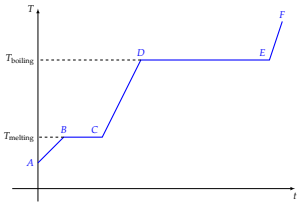
- E_p (gas) $>$ E_p (liquid) $>$ E_p (solid)[1]

[1] Ice melting is a counter-example for the separation: water is denser than ice. E_p still rises because hydrogen bonds are broken.

Internal energy of an ideal gas

No intermolecular forces, so $E_p =$ ____ and the energy is purely kinetic. Each molecule has $\frac{3}{2}kT$, so for N molecules

the internal energy of an ideal gas is _____ to its temperature.



Temperature against time for steady heating.

Change of state

- AB (solid heating): T rises so E_k _____; separation unchanged so E_p is _____
- BC (_____): T constant so E_k _____; bonds break so E_p _____
- CD (liquid heating): E_k _____, E_p constant
- DE (_____): E_k constant, E_p _____
- EF (gas heating): E_k _____; no forces so $E_p = 0$ constant

Question 22.3 Why is the specific latent heat of vaporisation much greater than that of fusion?

Evaporation

Evaporation: a liquid changes to gas _____. Molecules move at various speeds; the fastest near the surface escape.

- **cooling effect**: the most energetic molecules leave, so the mean E_k of those remaining _____ and the liquid cools
- the rate increases with _____ and with _____

	boiling	evaporation
where	_____	_____
temperature	_____	_____
bubbles	_____	_____
rate	_____	_____

First law of thermodynamics

The _____: the _____ of a system equals the _____ it plus the _____ it:

It is the law of _____. Sign conventions:

- $Q > 0$ if heat is supplied to the system; $Q < 0$ if it is released
- $W > 0$ if work is done *on* the system (compression, V decreases); $W < 0$ if the system does work (expansion, V increases)

Heat: $Q = cm\Delta T$ with no change of state, $Q = Lm$ during one. Work at _____:[2]

(magnitude)

If the volume does not change, _____ is done.

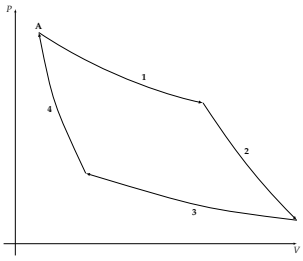
[2] If p varies, $W = \int p\,\mathrm{d}V$: the area under the p–V graph.

Example 22.5 A gas is heated with 25 kJ of energy and expands by 0.10 m^3 at a constant pressure of 150 kPa. Find the change in internal energy.

Example 22.6 Use internal energy and the first law to explain why boiling water needs a heat supply.

Example 22.7 Explain, using the first law, why the air in a bicycle tyre gets warmer as you pump.

Gas cycles

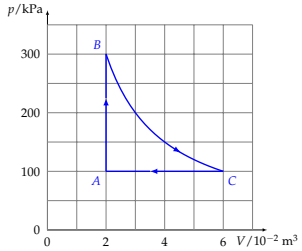


A Carnot cycle, from A.

The cycle returns to A, so over the cycle $\Delta U =$ ____.

- 1 _____: $\Delta U = 0$; gas does work so it must _____
- 2 _____: $Q = 0$; gas does work so U and T _____
- 3 _____: $\Delta U = 0$; work done on the gas so it _____
- 4 _____: $Q = 0$; work done on the gas so U and T _____

Example 22.8 Complete the table for the cycle: stage 1: $Q =$(a), $W = -936$ J, $\Delta U =$(b); stage 2: $Q = 0$, $W =$(c), $\Delta U =$(d); stage 3: $Q =$(e), $W = +702$ J, $\Delta U = 0$; stage 4: $Q =$(f), $W = +844$ J, $\Delta U = +844$ J.



Cycle ABCA for 0.80 mol of ideal gas.

Example 22.9 0.80 mol of an ideal gas goes round the cycle $ABCA$ shown. $T_A = 300$ K and the magnitude of the work from B to C is 6570 J. For each stage find W, Q and ΔU.

Question 22.4 Show that the thermal energy needed to raise the temperature of n mol of an ideal monatomic gas by 1.0 K at constant volume is $\frac{3}{2}nR$.

Question 22.5 Two identical balloons A and B hold the same gas at the same temperature and receive the same heat. A's volume is fixed; B may expand. Compare their final temperatures.

Temperature and thermometers

Thermal equilibrium

Heat flows spontaneously from _____. Two objects at the same temperature are in **thermal equilibrium**: there is _____.

_____: if A and B are each in thermal equilibrium with C, then A and B are in _____ with each other.

Question 22.6 A student says temperature measures the amount of heat in an object. Why is this wrong?

Absolute zero

Mean molecular K.E. is a microscopic measure of T, so the lowest temperature occurs when the molecules have _____: **absolute zero**.[3]

The Kelvin scale is _____: its zero does not depend on any particular substance. More precisely:

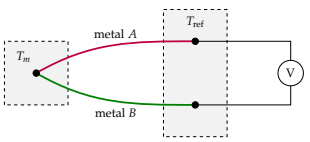
(273.15 here; the rest of the course uses 273.)

[3] Quantum effects mean the K.E. is never exactly zero, and 0 K cannot be reached in a finite number of steps (third law).

Thermometers

- **liquid-in-glass**: a liquid _____ as it warms
- **resistance temperature detector**: _____ of a metal wire or thermistor changes with temperature
- **thermocouple**: a _____ appears between junctions at different temperatures; one junction is at a known reference temperature

Features of a thermometer: *range*, *sensitivity* (small changes detected), *response time*, *linearity*.



A thermocouple.

	liquid-in-glass	RTD wire	thermistor	thermocouple
range	narrow	wide	narrow	very wide
sensitivity	low	fair	high	high
response time	slow	fast	fast	very fast
linearity	good	good	limited	non-linear