Energy and heat

In Mechanics you discussed and practiced the conservation of mechanikal energy (= kinetic + potential energy).
The energy was conserved for conservative forces, but it was "lost" if friction or air resistance was involved.
This energy was not really "lost", but used to, for example, increase the temperature of the objects.
To properly describe this, we need to account for <u>internal energy</u> — the ~~w~~ energy hidden in ~~motion~~ ~~in~~ chaotic (random) motion of individual atoms

Example: a meteorite moving through the atmosphere, some fraction of its mechanical energy is transferred into heating itself and the air around it.

<u>Macroscopic description</u>

Some of mechanical energy of a meteorite as a whole is transfered into internal energy of metal and surrounding.

<u>Microscopic description</u>

as surface ~~met~~ atoms of the meteorite collide with air molecules, some of their organized motion is transformed into chaotic, so the fraction of atom's internal energy (due to random motion) increases

Formal definition of the internal energy

Total energy of the system minus kinetic and potential energy of the object as a whole.

or

The sum of the mechanical energy (kinetic + potential) of the random motion particles that form the system

Ideal gas → no interaction → only kinetic energy

For monoatomic gas (no internal structure)

one particle $\langle K \rangle = \frac{3}{2} k_B T$

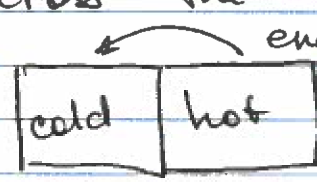
Internal energy $E_{int} = N \cdot \langle K \rangle = \frac{3}{2} N k_B T = \frac{3}{2} nRT$

Since for solids and liquids interactions b/w atoms is necessary, the calculations of the internal energy become complicated. We can still assume it is proportional to the temperature T

Heat describes specific kind of energy added or removed from the system

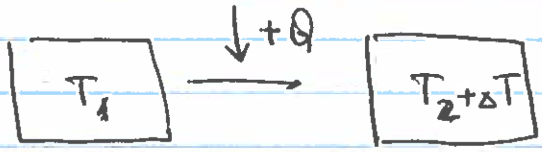
Heat is the form of energy crossing the boundary of a thermodynamic system by virtue of a temperature difference across the boundary

energy flow = heat



$T_c < T_h$

For complex systems (solids, liquids) we correlate the amount of ~~energy~~ heat added or removed from empirical data



$$Q = m \cdot c \cdot \Delta T$$

↑ mass ↑ temperature change

c - Specific heat capacity

$Q > 0$ — energy is added to the system $\Delta T > 0$

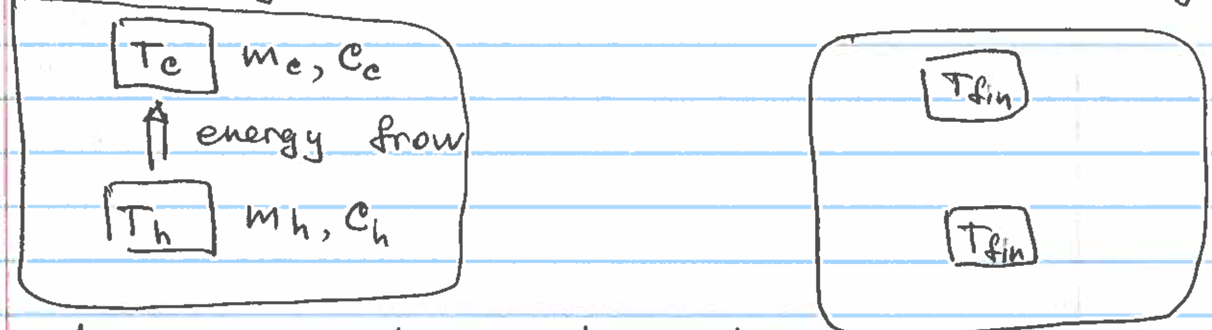
$Q < 0$ — energy is removed, $\Delta T < 0$

Thermally isolated system → $Q = 0$, no energy exchange with the world

What happens when two objects of different temperature are brought in contact inside thermally isolated environment?

~~Before~~

Immediately on contact After a long time



Amount of heat lost by a hot object equal amount of heat gain by a cold one

$$Q_{hot} + Q_{cold} = 0$$

<0 >0

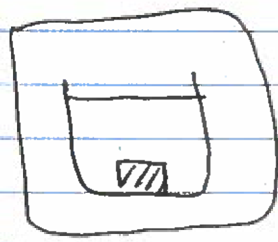
$$Q_{hot} = m_h c_h (T_{fin} - T_h) < 0$$

$$Q_{cold} = m_c c_c (T_{fin} - T_c) > 0$$

$$m_h c_h (T_{fin} - T_h) + m_c c_c (T_{fin} - T_c) = 0$$

Example problem : unknown heat capacity

A small test object of mass m_{test} is dropped into a thermally isolated cup of water (calorimeter)



initial:

$m_{test} = 0.3\,kg$ $\quad$ $m_{water} = 1\,kg$

$T_{test} = 100°C$ $\quad$ $T_{water} = 25°C$

$c_{water} = 4186\ J/kg\,°C$

Final temperature is $T_{fin} = 27°C$

$$Q_{water} = m_w c_w (T_{fin} - T_w) > 0$$

$$Q_{test} = m_{test} c_{test} (T_{fin} - T_{test}) < 0 = -Q_{water}$$

$$m_w c_w (T_{fin} - T_w) = m_{test} c_{test} (T_{test} - T_{fin})$$

$$c_{test} = \frac{m_w c_w (T_{fin} - T_w)}{m_{test} (T_{test} - T_{fin})} = 4186 \frac{J}{kg \cdot °C} \frac{1\,kg}{0.3\,kg} \frac{2°C}{73°C}$$

$$c_{test} = 382\ J/kg\,°C$$

In principle, you can figure out what was the metal used for this test knowing its specific heat capacity.

But what if the test block was very large and very hot? Then some of the water would evaporate

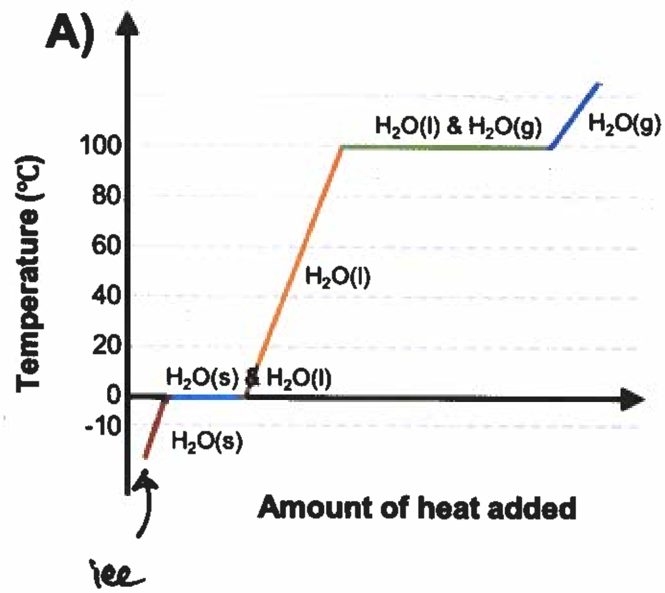
It takes energy to break the bond b/w molecules in liquid and let them fly freely, even if their kinetic energy stays the same
(like a rocket escaping Earth's gravity)
Extra heat is needed during phase transitions

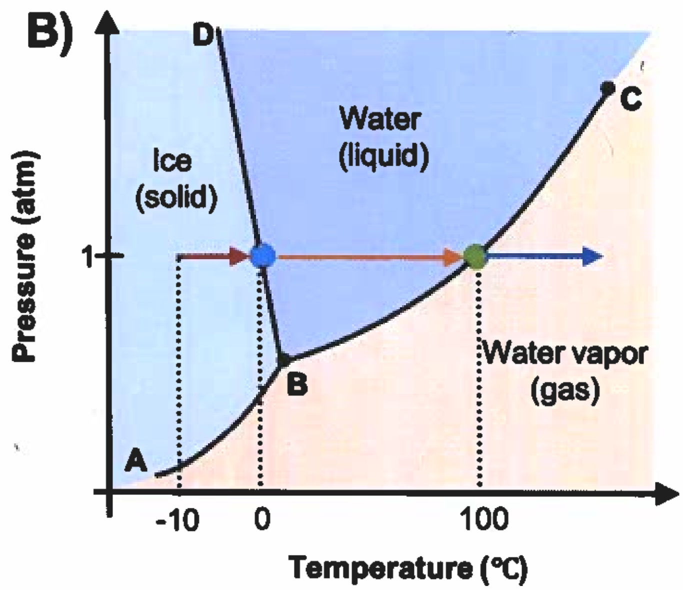
$Q = L \cdot m$ L – latent heat

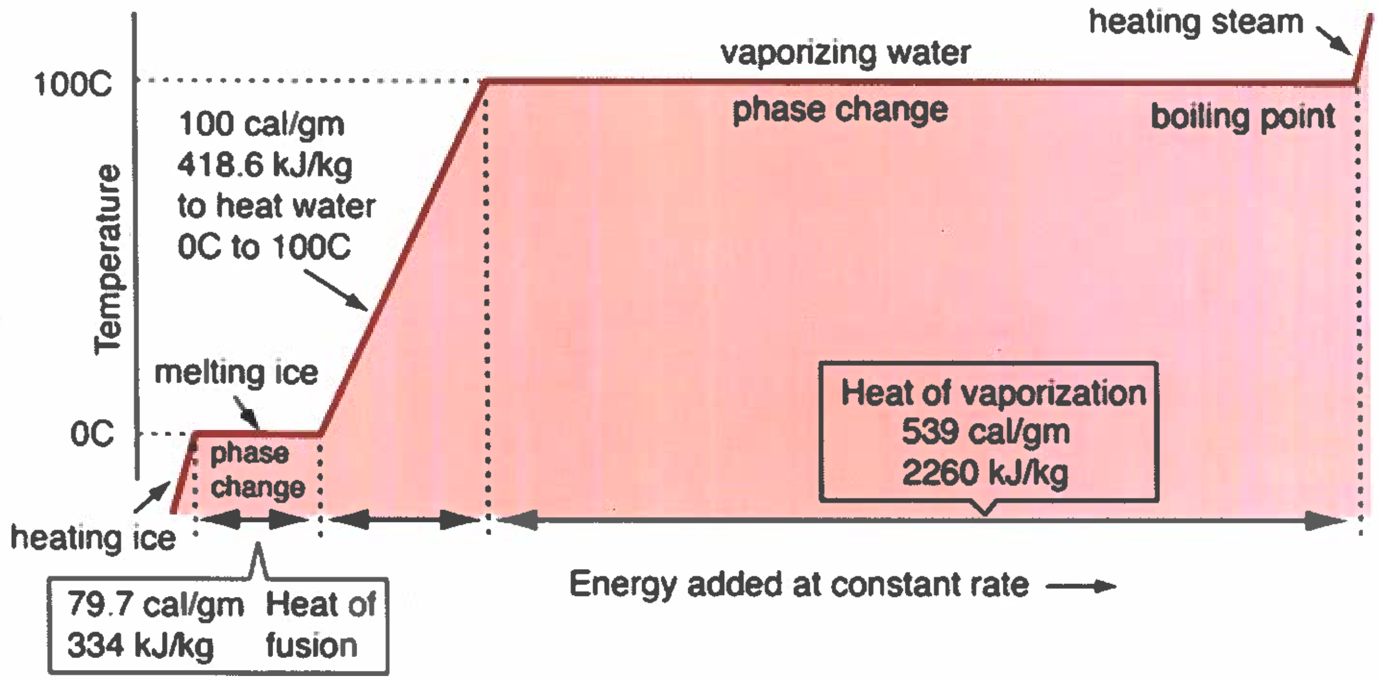
If we start heating a block of ice

ice only temperature increases $\xrightarrow{T=0°C}$ ice + water mixture @ $T = 0°C$ → water only temperature increases $\xrightarrow{T=100°C}$

→ water + steam @ $T = 100°C$ → steam (gas) only temperature increases


A)
Temperature (°C)
100
80
60
40
20
0
-10
$H_2O(l)$ & $H_2O(g)$
$H_2O(g)$
$H_2O(l)$
$H_2O(s)$ & $H_2O(l)$
$H_2O(s)$
Amount of heat added
ice


B)
Pressure (atm)
D
Water (liquid)
Ice (solid)
C
1
Water vapor (gas)
B
A
-10
0
100
Temperature (°C)


heating steam
vaporizing water
100C
phase change
boiling point
100 cal/gm
418.6 kJ/kg
to heat water
0C to 100C
Temperature
melting ice
Heat of vaporization
539 cal/gm
2260 kJ/kg
0C
phase
change
heating ice
Energy added at constant rate
79.7 cal/gm
334 kJ/kg
Heat of
fusion