PHAS1000- THERMAL PHYSICS

Lecture 2

Zeroth Law

Overview – This lecture

We will look at:

- Heat
- Internal Energy
- Thermal Equilibrium
- Zeroth Law
- Thermal Reservoir
- Isolated Thermal System

Questions

What is HEAT?

When you heat an object, where does the HEAT GO?

What is THERMAL EQUILIBRIUM?

Do objects have to be in contact to be in thermal equilibrium?

Definitions

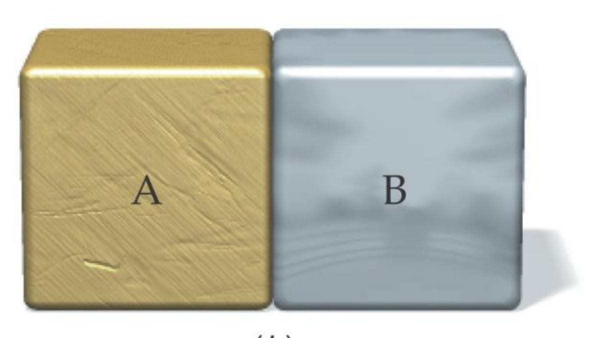
- **Heat (Q)** is a flow of energy caused by a temperature difference

- Heat absorbed by an object is stored as **internal energy (U)**

- **Internal energy** is the kinetic energy and potential energy of the atoms or molecules

- **Thermal equilibrium** is when heat flow ceases, when temperatures are equal

Zeroth (0^{th}) Law of Thermodynamics



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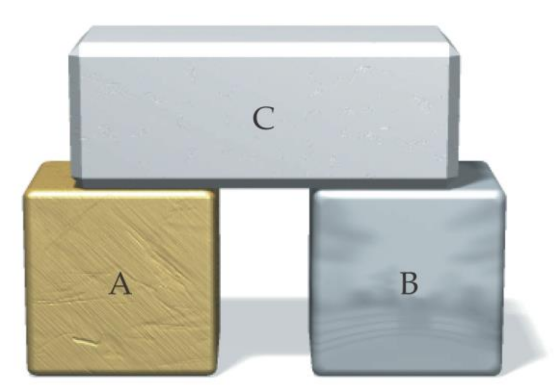

(a)

ZEROTH LAW: If two objects are separately in thermal equilibrium with a third, then they are in thermal equilibrium with each other.

Zeroth (0^{th}) Law of Thermodynamics

1920s	0^{th} Law: Defines temperature
Mid 1800s	1^{st} Law: Conservation of energy
Mid 1800s	2^{nd} Law: Entropy of isolated system can never decrease
1906	3^{rd} Law: Entropy of perfect crystal tends to zero at absolute zero

Question

Object X has a higher temperature than object Y

If X and Y are both placed in contact with a thermal reservoir at higher temperature than X, more heat will flow to Y than to X.

Is this statement true…..?

A Always true
B Never true
C Depends on the objects

Thermal reservoir is LARGE source (or sink) of heat, so that its temperature does not change when heat is lost or gained.

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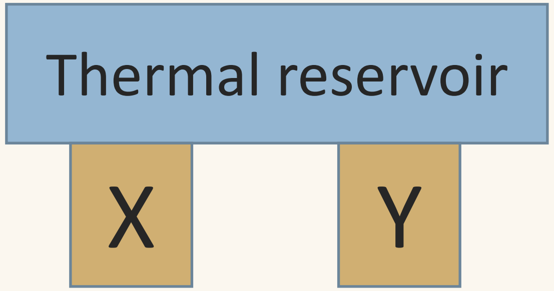
Answer

Object X has a higher temperature than object Y

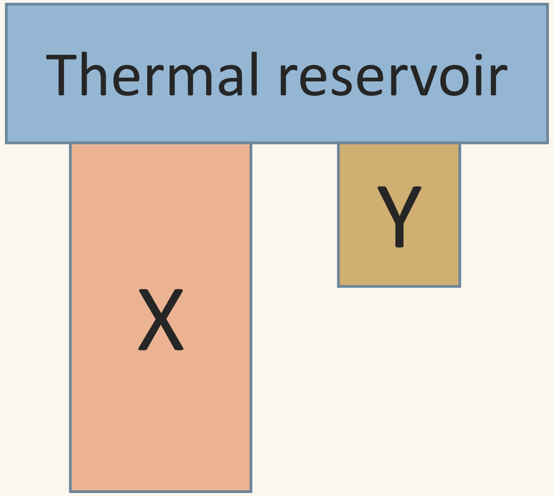
If X and Y are both placed in contact with a thermal reservoir at higher temperature than X, more heat will flow to Y than to X.

Is this statement true…..?



$$\Delta T_x < \Delta T_y$$

$$Q = mc\Delta T$$



A Always true
B Never true
C Depends on the objects

Specific Heat Capacity

Specific heat capacity is the heat needed to raise the temperature of *1 kg* by 1K

c = heat capacity per kg

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

C = mc = heat capacity of whole object (J/K)

Q = heat added to system (J)

c = specific heat capacity (J/kg.K)

m = mass of sample
(*not to confuse with mass of molecule*)

ΔT = change in temperature

Latent Heat

Latent heat is the heat needed to change the phase

$$Q = mL$$

L = latent heat (J/kg)

m = mass of sample

Q = heat energy (J)

Latent Heat

Which of the following is *false*?

A When melting a substance heat energy is required to overcome attractions between the molecules

B There is no change of temperature during a phase change

C Heat supplied to change the phase of a material is used to increase the potential energy of the molecules

D When a material freezes some of the latent heat released comes from the reduced kinetic energy of the molecules.

Data

Specific heat capacity

Substance	c, kJ/kg·K
Aluminum	0.900
Bismuth	0.123
Copper	0.386
Glass	0.840
Gold	0.126
Ice (−10°C)	2.05
Lead	0.128
Silver	0.233
Tungsten	0.134
Zinc	0.387
Alcohol (ethyl)	2.4
Mercury	0.140
Water	4.18

Latent heat

Normal Melting Point (MP), Latent Heat of Fusion (L_f), Normal Boiling Point (BP), and Latent Heat of Vaporization (L_v) for Various Substances at 1 atm

Substance	MP, K	L_f, kJ/kg	BP, K	L_v, kJ/kg
Alcohol, ethyl	159	109	351	879
Bromine	266	67.4	332	369
Carbon dioxide	—	—	194.6†	573†
Copper	1356	205	2839	4726
Gold	1336	62.8	3081	1701
Helium	—	—	4.2	21
Lead	600	24.7	2023	858
Mercury	234	11.3	630	296
Nitrogen	63	25.7	77.35	199
Oxygen	54.4	13.8	90.2	213
Silver	1234	105	2436	2323
Sulfur	388	38.5	717.75	287
Water	273.15	333.5	373.15	2257
Zinc	692	102	1184	1768

† These values are for sublimation. Carbon dioxide does not have a liquid state at 1 atm.

Question

A 25 g gold ring at 50°C is dropped into a 50 g of cold water at 2.0°C.

What is the final temperature when they reach thermal equilibrium?

Heat lost by gold ring = heat absorbed by water

$$m_g c_g \Delta T_g = m_w c_w \Delta T_w$$

$$m_g c_g (T_g - T_f) = m_w c_w (T_f - T_w)$$

Ans = 2.7 °C

What are these and how do they work?

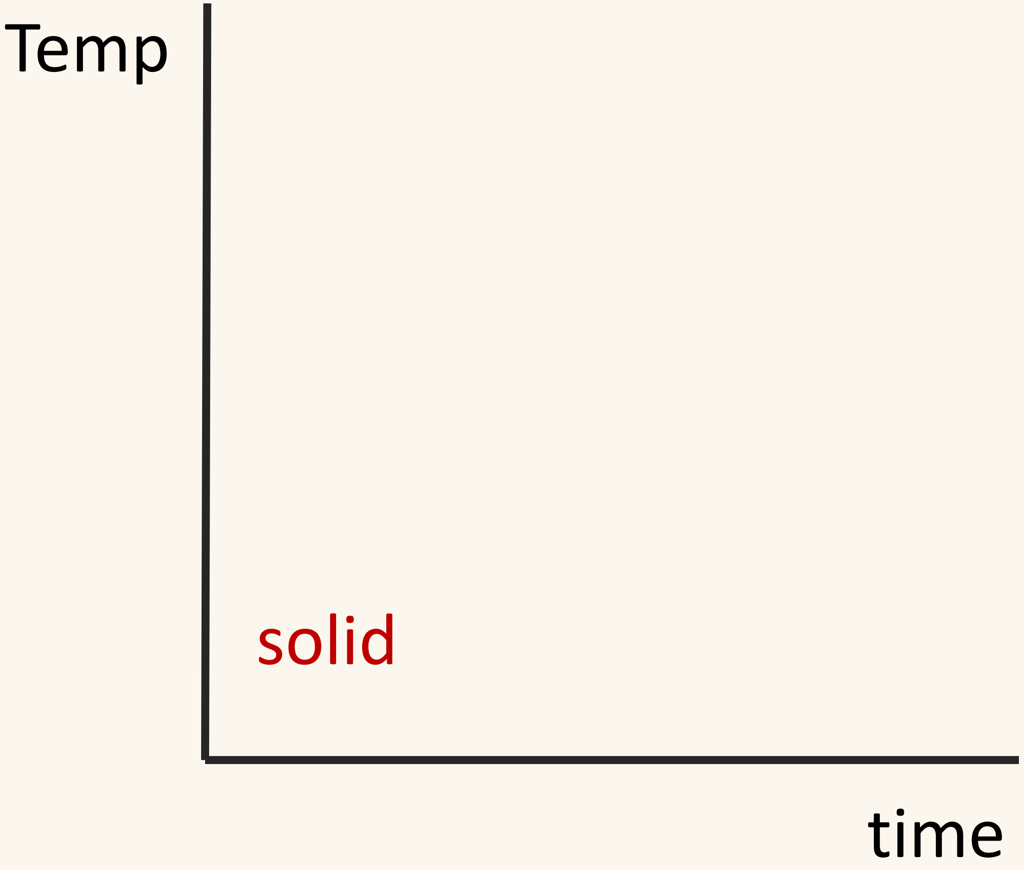
Hand warmers

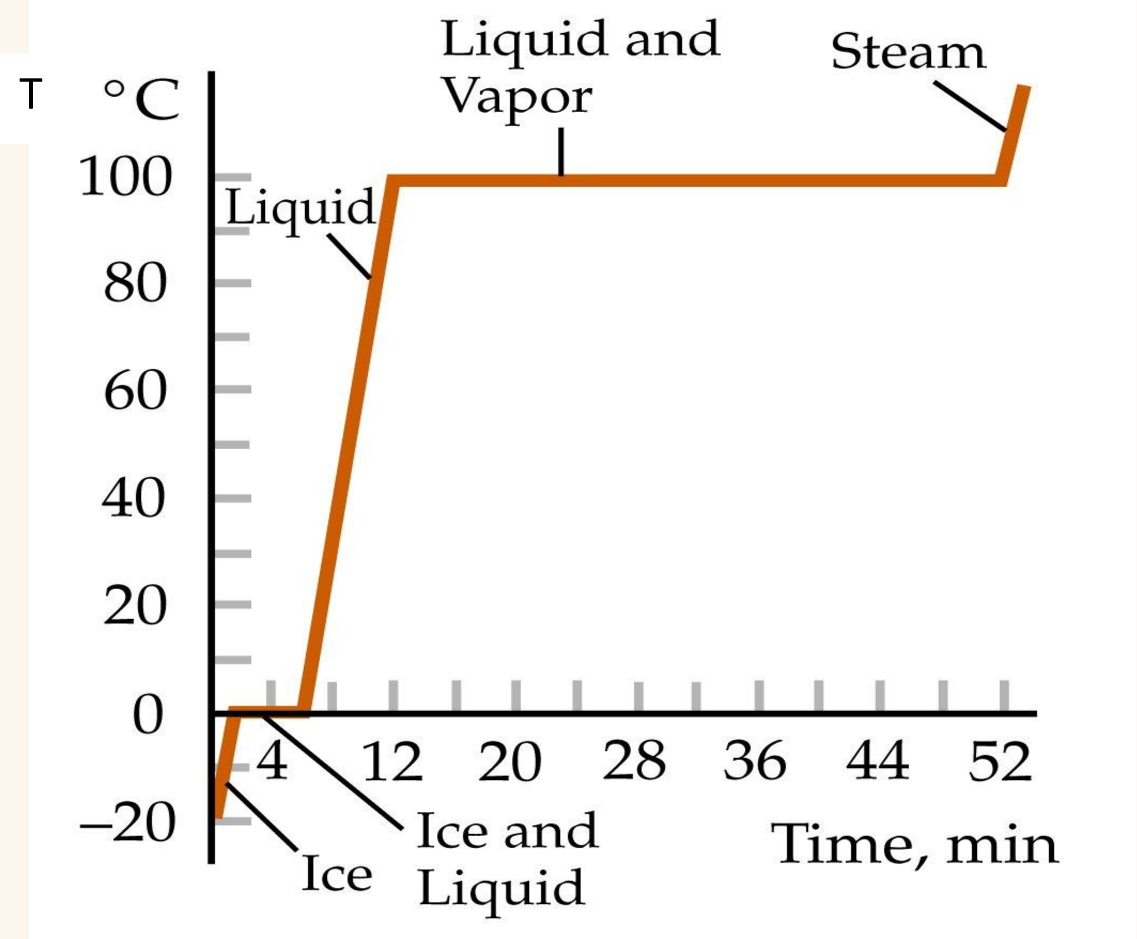
Liquid is supersaturated salt solution

Shock wave triggers crystallisation

Exothermic process, latent heat given out

Heating at constant rate





http://www.youtube.com/watch?v=w2mj-Sq2oeo&feature=related

Problem

Add 50 g of hot water at 95°C

Polystyrene cup half full of liquid nitrogen (200 g)

What is left in the cup after the water is added?

What data do you need?

Data

Specific heat capacity

Substance	c, kJ/kg·K
Aluminum	0.900
Bismuth	0.123
Copper	0.386
Glass	0.840
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Solution

heat lost by water = heat gained by nitrogen

water : cools and freezes and cools further

nitrogen : at its bp , vaporises , and then disperses into the air

nitrogen : $Q = mL = 0.2 \times 199 \times 10^3$ $= 39800\ J$

water : cooling $Q = mc\Delta T = 0.05 \times 4.18 \times 10^3 \times (95 - 0)$ $= 19855\ J$

water freezing $Q = mL = 0.05 \times 333.5 \times 10^3$ $= 16675\ J$

heat lost by water so far

$19855 + 16675 = 36530$

heat taken from ice cooling

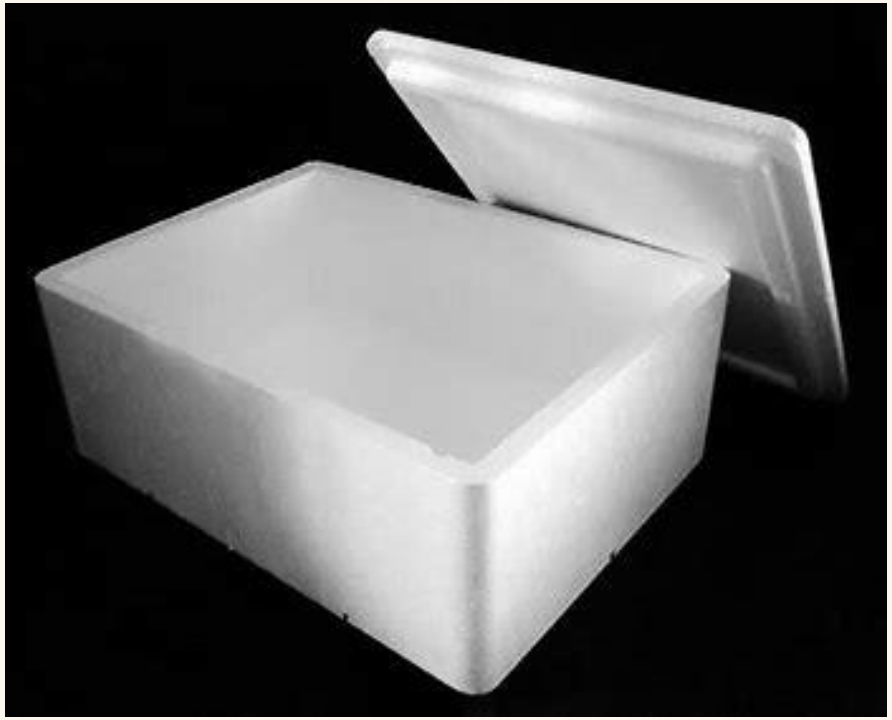
$= 39800 - 36530 = 3270\ J$

ice cooling $Q = mc\Delta T$

$$\Delta T = \frac{Q}{mc} = \frac{3270}{0.05 \times 2.05 \times 10^3} = 31.9\ ^\circ C$$

So we are left with ice at $-31.9\ ^\circ C$

Isolated thermal system



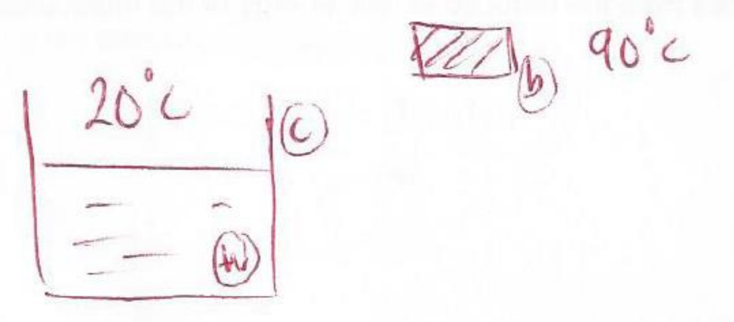
There is no such thing as a perfectly sealed and insulated box

But we need to define a boundary to our calculations.

Calorimeter

A small metal block of mass 160g is heated in an oven to 90°C. It is then immediately placed in a copper calorimeter of mass 180g containing 150g of water initially at 20°C.

If the final temperature of the combined system is 32°C, suggest a possible metal from which the block could be made.



heat lost by block = heat gained by calorimeter and water

$$Q = m_b c_b \Delta T_b = m_c c_c \Delta T_c + m_w c_w \Delta T_w$$

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Question

A glass contains 400g of water and has 6 ice cubes (of total mass 200g) floating in it, in thermal equilibrium with the water. If the glass is then heated by a 0.5kW heater, calculate:-

(i) the rate of melting of the ice

(ii) the time taken to melt all the ice

(iii) the rate of temperature rise once all the ice is melted

Ignore the heat capacity of the glass

Answer

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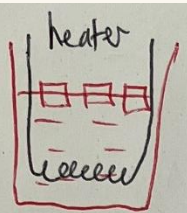


equilibrium of water and ice

$\therefore$ temp $= 0°C$

initially at heat goes into melting ice at 0°C

(i) $Q = mL$ $\quad P = \frac{dQ}{dt} = L\frac{dm}{dt}$

$$\frac{dm}{dt} = \frac{P}{L} = \frac{0.5\times10^{3}}{333.5\times10^{3}} = 1.5\times10^{-3}\ \text{kg/s} = 1.5\ \text{g/s}$$

(ii) $\frac{dm}{dt} = \frac{\Delta m}{\Delta t}$ $\quad \Delta t = \frac{\Delta m}{(dm/dt)} = \frac{200}{1.5} = 133.3\,s = 2.2\,\text{min}$

(iii) now all is water, so $M = 200g + 400g = 600g$

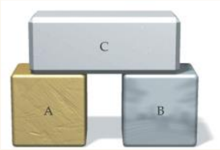
$Q = mc\Delta T$

$P = \frac{dQ}{dt} = mc\frac{dT}{dt}$

$$\frac{dT}{dt} = \frac{P}{mc} = \frac{0.5\times10^{3}}{600\times10^{-3}\times4.18\times10^{3}} = 0.199 \sim 0.2\ °C/s$$

Summary

Heat (Q) is a flow of energy caused by temperature difference



Zeroth law: Thermal equilibrium is when heat flow ceases

Heat absorbed by a body is stored as internal energy (U) as KE and PE