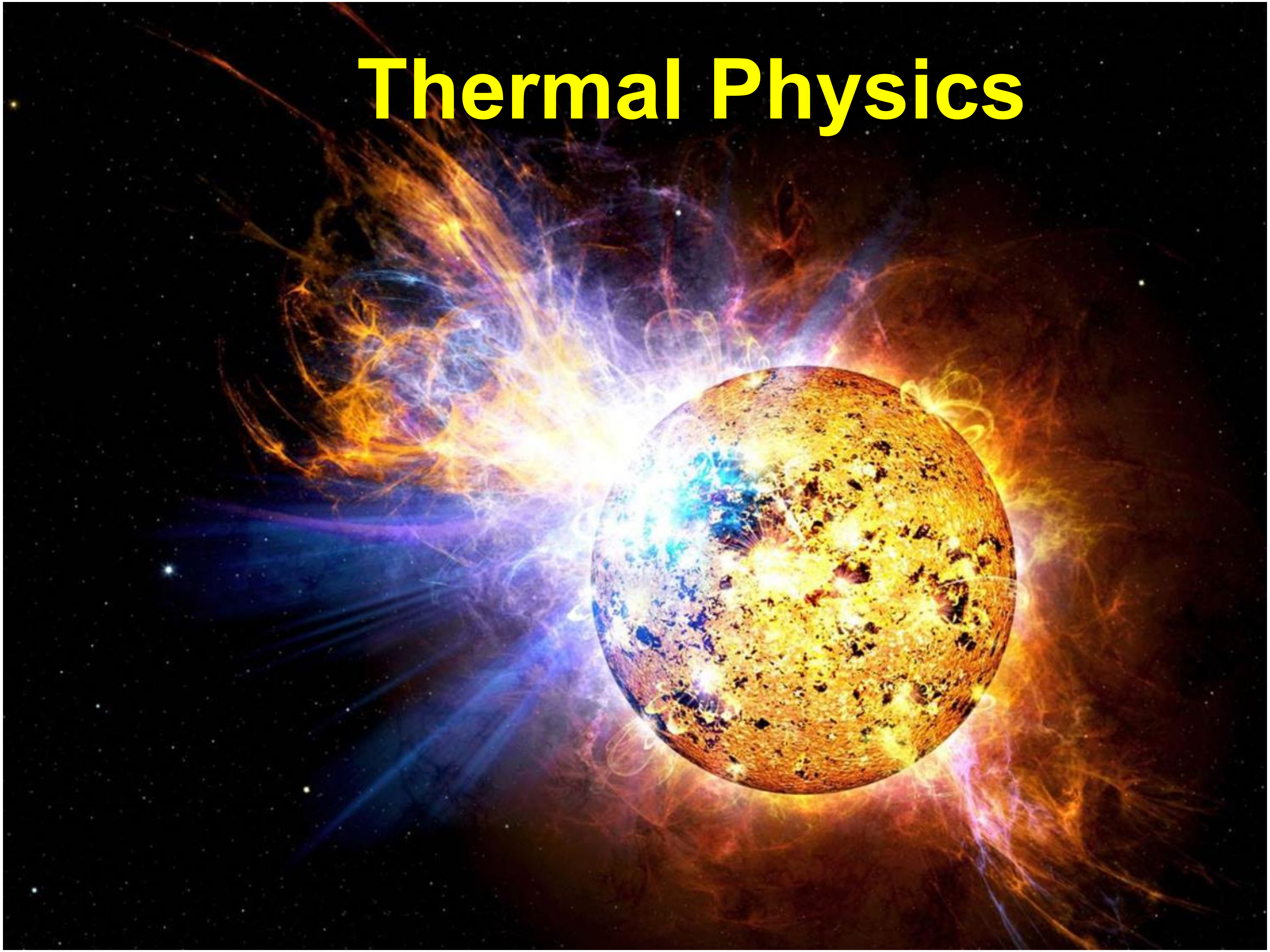
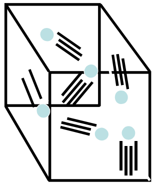
Thermal Physics



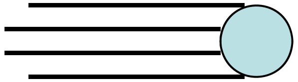
Forms of Energy

Energy comes in a variety of forms…

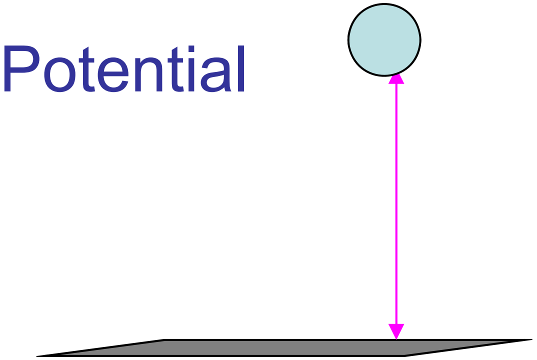
Internal



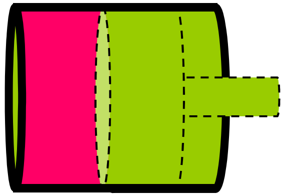
Kinetic



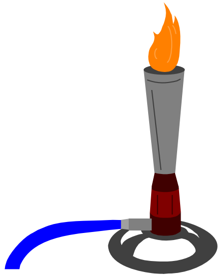
Potential



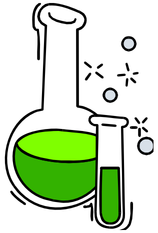
Mechanical



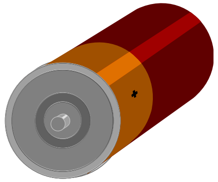
Heat



Chemical



Electrical



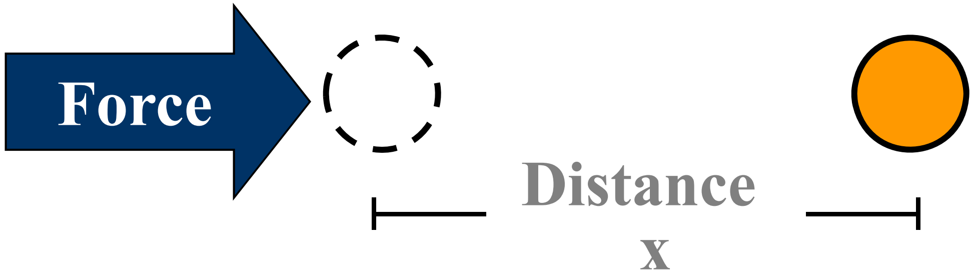
All energy forms have the same units, **Nm** or **Joules (J)**

Energy is defined as “the capacity to do **Work**”

Work is a Mechanical form of Energy:

$$\text{Work} = \text{Force} \times \text{Distance}$$

$$dW = F \times \Delta x$$



The Key Concepts in Thermal Physics

Thermal Physics can be explained in terms of three key quantities:

- Heat (Q)
- Internal Energy (U)
- Temperature (T)

In todays lesson we will consider these three quantities

Heat (Q) and Internal Energy (U)

- Heat is energy that **flows** from a higher temperature object to a lower temperature object because of differences in temperature.
- Note, heat always flows from hot to cold !!
- The heat that flows originates in the **Internal Energy** of the hot substance.
- When heat flows, the internal energy of the hot substance <u>decreases</u> and the internal energy of the cold substance <u>increases</u>.

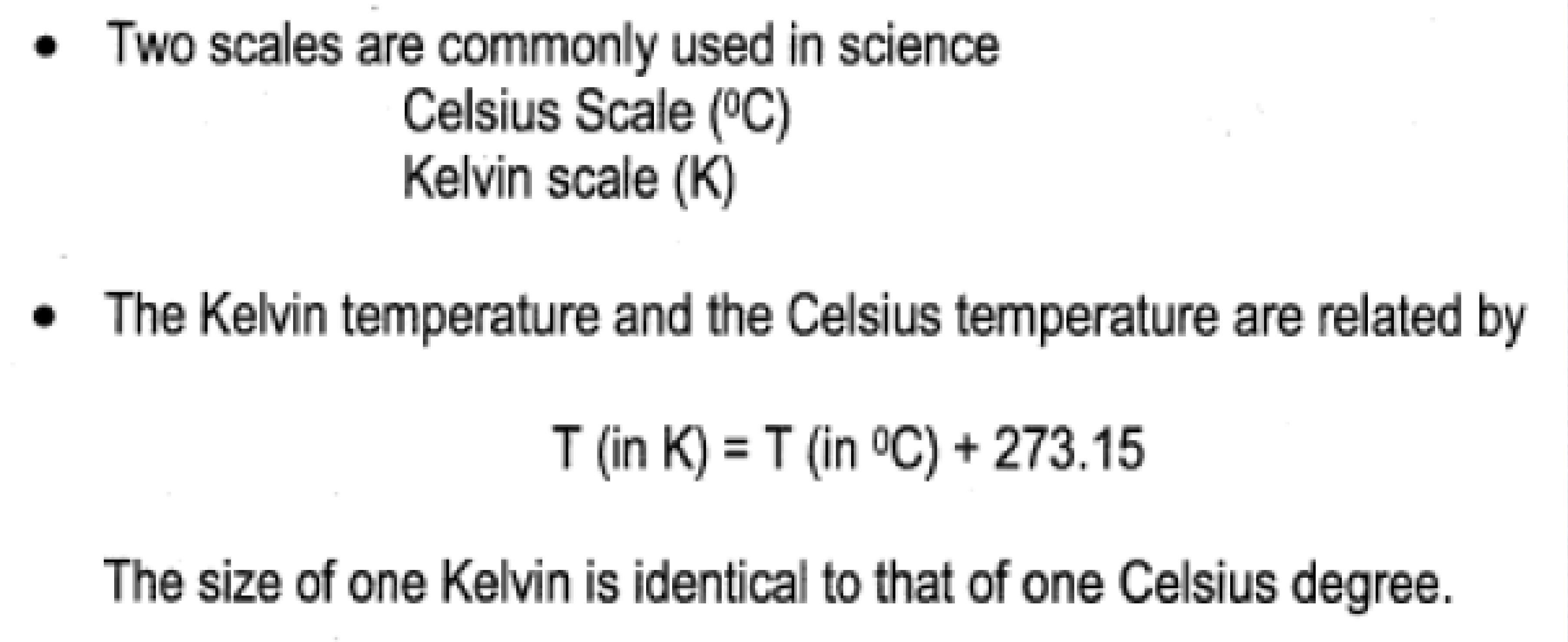
Internal Energy (U)

- **Internal Energy** is associated with the microscopic components of a system – atoms and molecules.
- **Internal Energy** includes kinetic and potential energy associated with the motions of atoms or molecules in the system.
- **Internal Energy** is the **TOTAL** energy of all the molecules in the object.

Temperature

- **Temperature** is a measure of the hotness or coldness of a body.
- Temperature is related to the internal energy.
- Temperature in Kelvins is a measure of the **average** kinetic energy of individual molecules.
- Note, the <u>direction</u> of heat flow between two objects depends upon their temperatures **NOT** on how much internal energy each object has !

Temperature Scales



- Two scales are commonly used in science

  Celsius Scale (^{0}C)

  Kelvin scale (K)

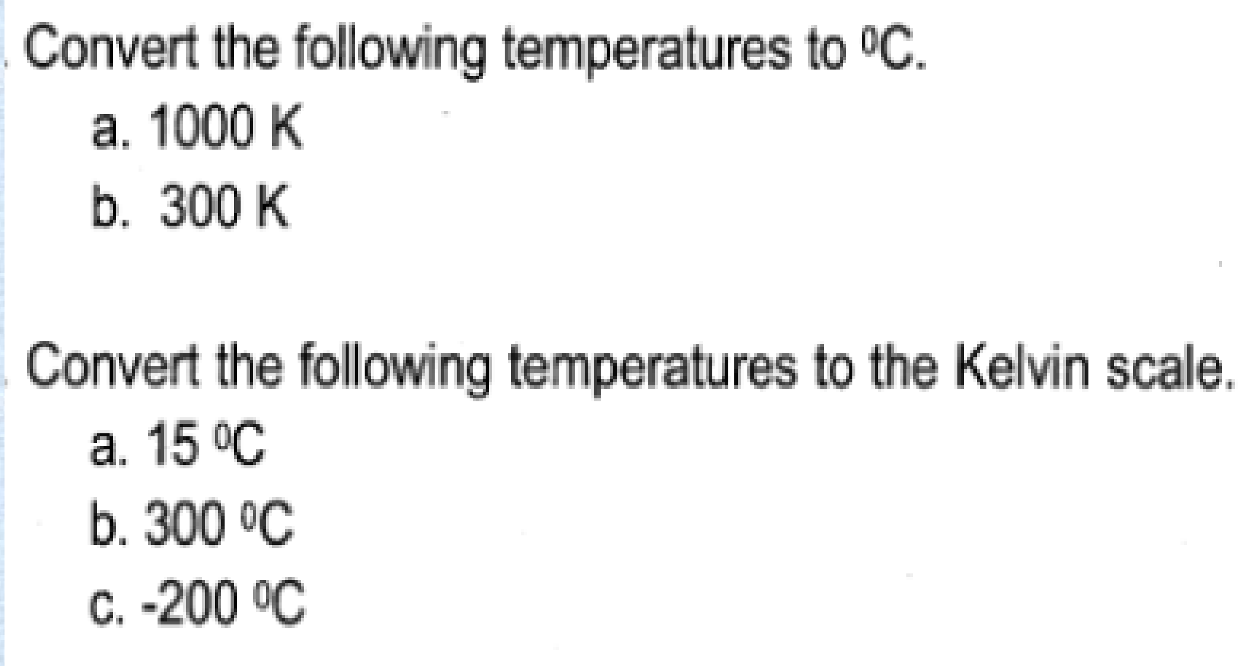
- The Kelvin temperature and the Celsius temperature are related by

$$T \text{ (in K)} = T \text{ (in } {}^0\text{C)} + 273.15$$

The size of one Kelvin is identical to that of one Celsius degree.

- Note, we write temperature in Kelvin without the degree symbol. For example, we would write 20°C as 293.15K not 293.15°K.

Temperature Scales - Student Problems



Convert the following temperatures to ^{0}C.

a. 1000 K

b. 300 K

Convert the following temperatures to the Kelvin scale.

a. 15 ^{0}C

b. 300 ^{0}C

c. -200 ^{0}C

Thermal Physics Worksheet 1 – ANSWERS

Heat and Temperature

Q1 HEAT IS ENERGY THAT FLOWS FROM HIGH TEMPERATURE TO A LOWER TEMPERATURE

TEMPERATURE IS MEASURE OF HOTNESS OR COLDNESS OF A BODY

Q2 NO – SOME HEAT FROM COFFEE FLOWS TO TABLE

WHEN BOTH COFFEE AND TABLE HAVE REACHED SAME TEMPERATURE

Q3 A AND B SAME TEMPERATURE

C AT DIFFERENT TEMPERATURE TO A AND B

Q4 HIGH PRESSURE ON OCEAN FLOOR KEEPS WATER AT LIQUID STATE.

(SAME PRINCIPLE AS IN A CAR RADIATOR !)

Q5 DECREASE PRESSURE

Q6 (a) $1{,}000°K = 1000 - 273.15°C = \underline{726.85°C}$

(b) $300°K = 300 - 273.15°C = \underline{26.85°C}$

Q7 (a) $15°C = 15 + 273.15° = \underline{288.15°K}$

(b) $300°C = 300 + 273.15 = \underline{573.15°K}$

(c) $-200°C = -200 + 273.15° = \underline{73.15°K}$

Energy Conservation

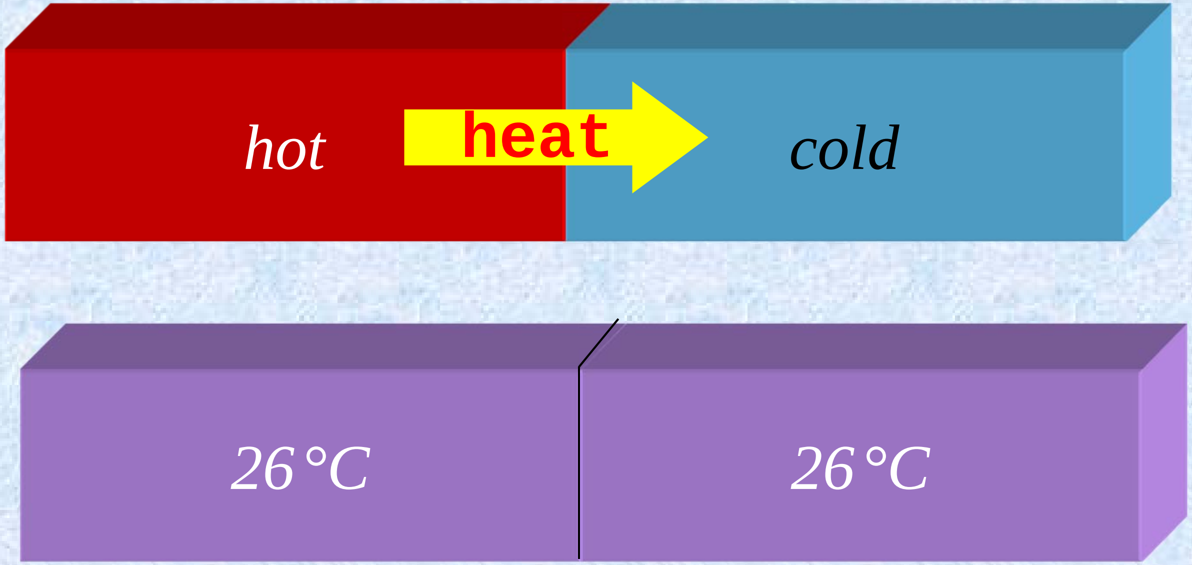
The **First Law of Thermodynamics** states that total energy is always conserved in a system. The total amount of energy and matter in the Universe remains constant. Energy merely changes from one form to another:

- energy cannot be created nor destroyed
- energy can only change from one form to another

$$Energy(E) = \text{constant}$$

Thermal Equilibrium

Two bodies are said to be at thermal equilibrium if they are at the same temperature. This means there is no net exchange of thermal energy between the two bodies. The top pair of objects are in contact, but since they are at different temps, they are not in thermal equilibrium, and energy is flowing from the hot side to the cold side.



No net heat flow

The two purple objects are at the same temp and, therefore are in thermal equilibrium. There is no net flow of heat energy here.

Thermal Equilibrium and the Zeroth Law of Thermodynamics

- If warm and cool objects are placed in thermal contact, ***heat*** flows from the warm to the cold object until ***thermal equilibrium*** is established.

Zeroth Law of Thermodynamics

- Two systems, separately in thermal equilibrium with a third system, are in thermal equilibrium with each other.
- If objects A and B are each in thermal equilibrium with object C, then A and B are in thermal equilibrium with each other
- Allows us to define temperature relative to an established standard.

Thermal Expansion

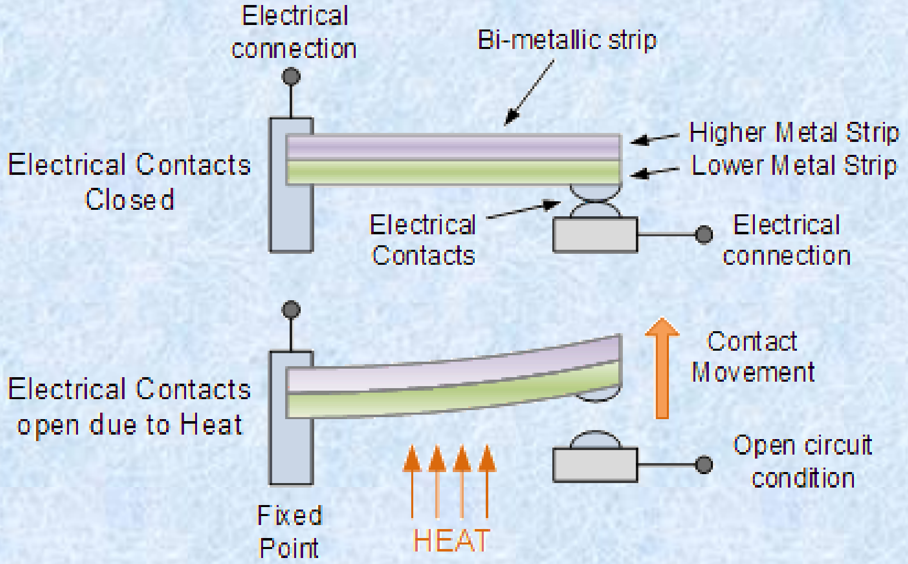
- Almost all materials expand when heated and contract when cooled.
- The property of linear thermal expansion is given symbol α.
- If the material is restrained in a system so that it is unable to expand, then stresses may develop in the system leading to buckling of components (train tracks):

Thermal Expansion

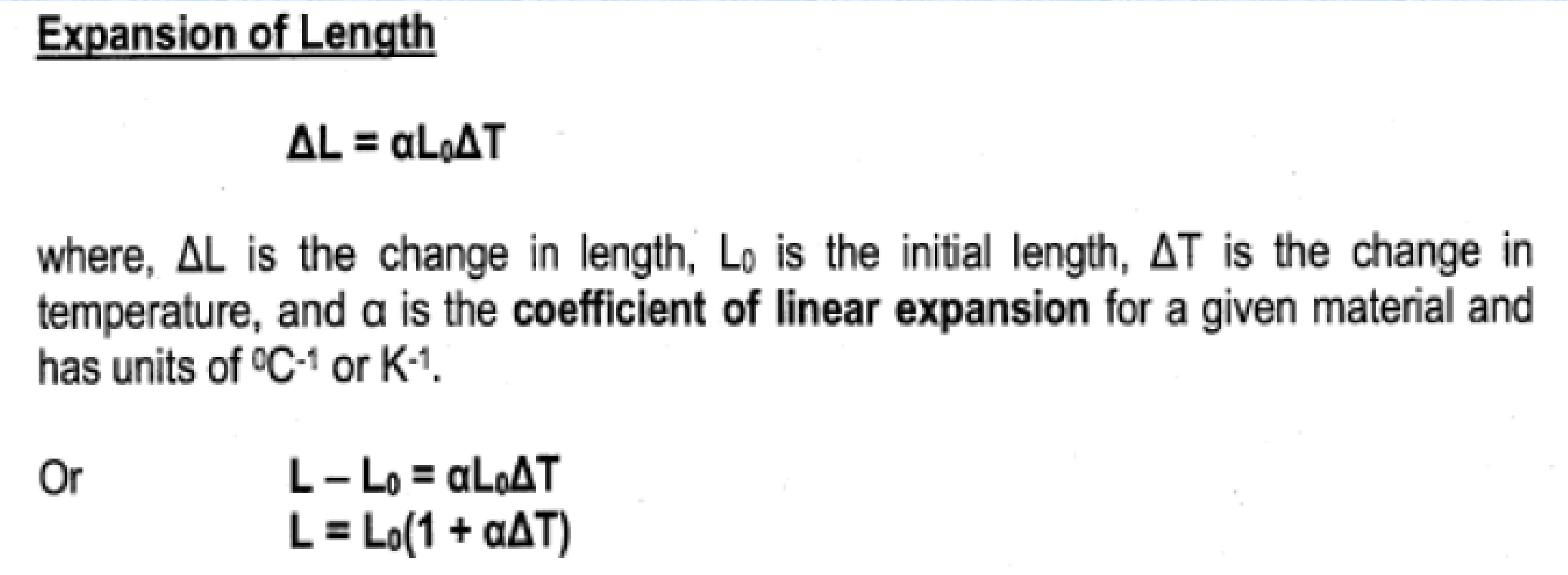
Fig. 18-9 When a Concorde flew faster than the speed of sound, thermal expansion due to the rubbing by passing air increased the aircraft's length by about 12.5 cm.

Thermal Properties - Expansion

- However, sometimes the properties of thermal expansion is advantageous; such as in bi-metallic temperature sensing switches.
- These switches use two different metals bonded together with very different coefficient values.
- In the switch shown below; $\alpha_{\text{(lower strip)}} > \alpha_{\text{(higher strip)}}$



Expansion of Length



Expansion of Length

$$\Delta L = \alpha L_0 \Delta T$$

where, ΔL is the change in length, L_0 is the initial length, ΔT is the change in temperature, and α is the **coefficient of linear expansion** for a given material and has units of $^0C^{-1}$ or K^{-1}.

Or

$$L - L_0 = \alpha L_0 \Delta T$$

$$L = L_0(1 + \alpha \Delta T)$$

Coefficients of Linear Expansion

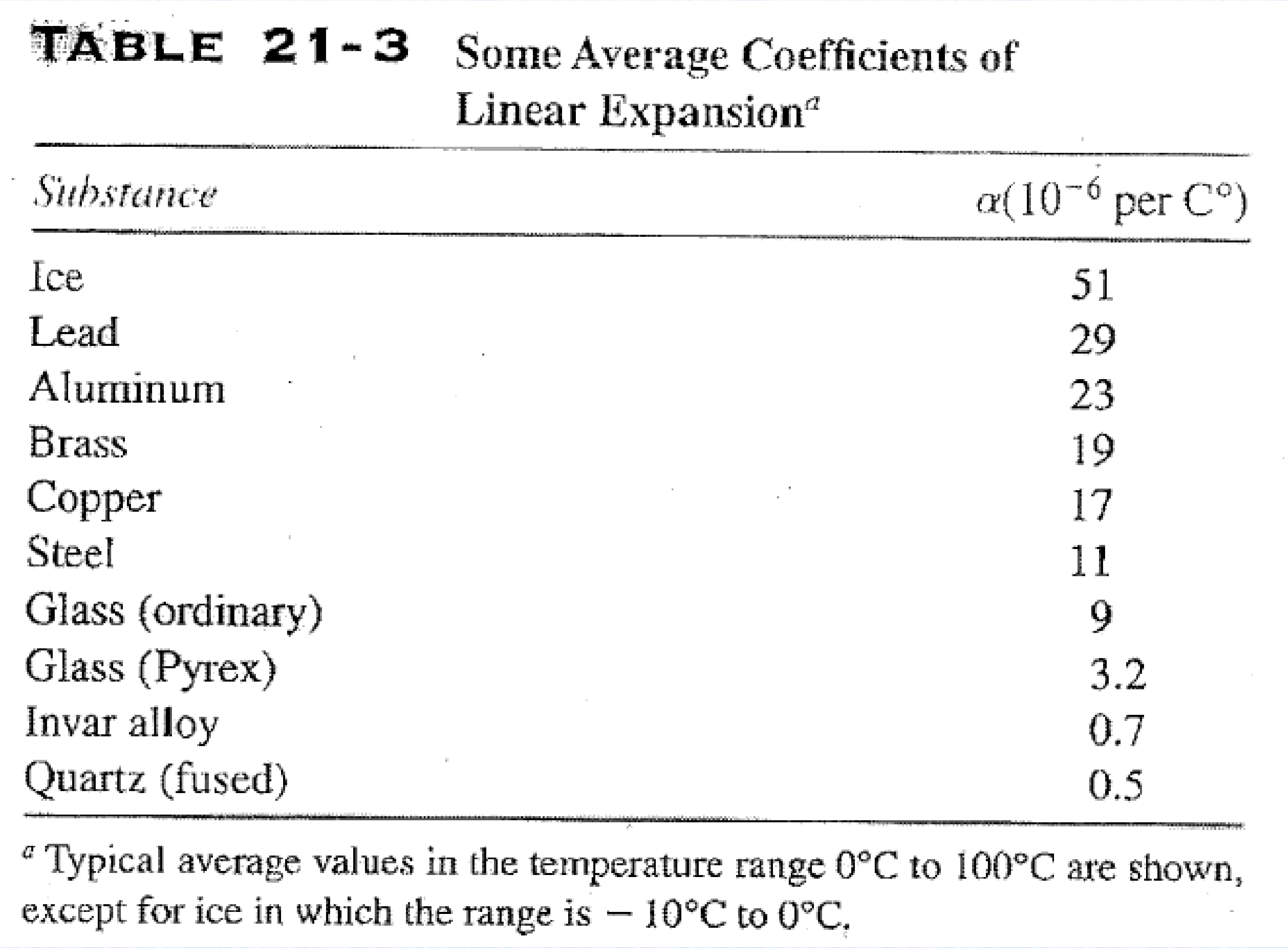
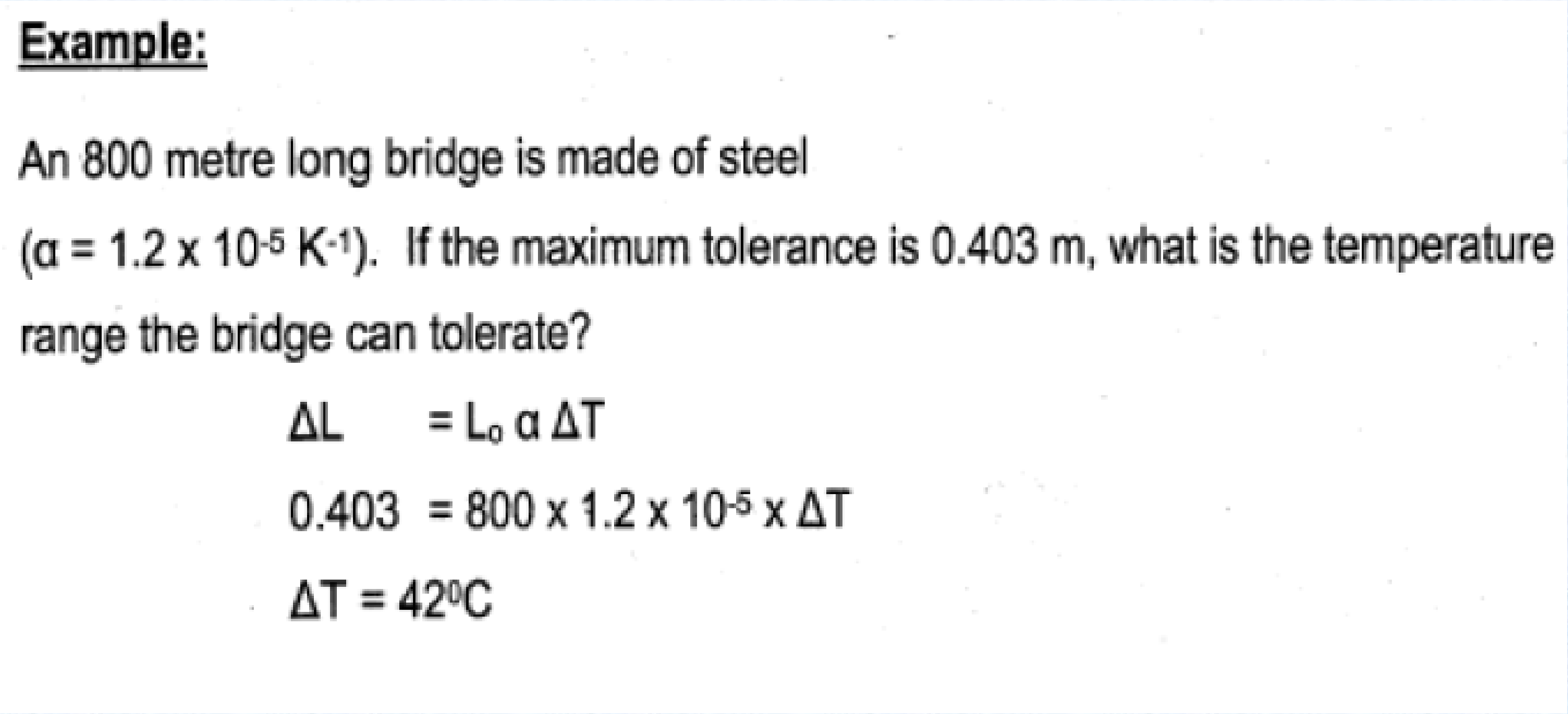


TABLE 21-3 Some Average Coefficients of Linear Expansion[a]

Substance	$\alpha(10^{-6}$ per C°)
Ice	51
Lead	29
Aluminum	23
Brass	19
Copper	17
Steel	11
Glass (ordinary)	9
Glass (Pyrex)	3.2
Invar alloy	0.7
Quartz (fused)	0.5

[a] Typical average values in the temperature range 0°C to 100°C are shown, except for ice in which the range is − 10°C to 0°C.

Expansion of Length



Example:

An 800 metre long bridge is made of steel ($\alpha = 1.2 \times 10^{-5}\ K^{-1}$). If the maximum tolerance is 0.403 m, what is the temperature range the bridge can tolerate?

$$\Delta L = L_0\ \alpha\ \Delta T$$

$$0.403 = 800 \times 1.2 \times 10^{-5} \times \Delta T$$

$$\Delta T = 42^0C$$

LINEAR EXPANSION:

SYDNEY H BRIDGE = 1150 m
MADE OF STEEL

$\alpha_{STEEL} = 11 \times 10^{-6}\ {}^\circ C^{-1}$

$= 11 \times 10^{-k}\ K^{-1}$

$$\boxed{LENGTH = L_0(1 + \alpha \Delta T)}$$

ΔT = CHANGE IN TEMPERATURE

L_0 (AT 25°C) = 1150

WHAT IS BRIDGE LENGTH
AT 40°C?

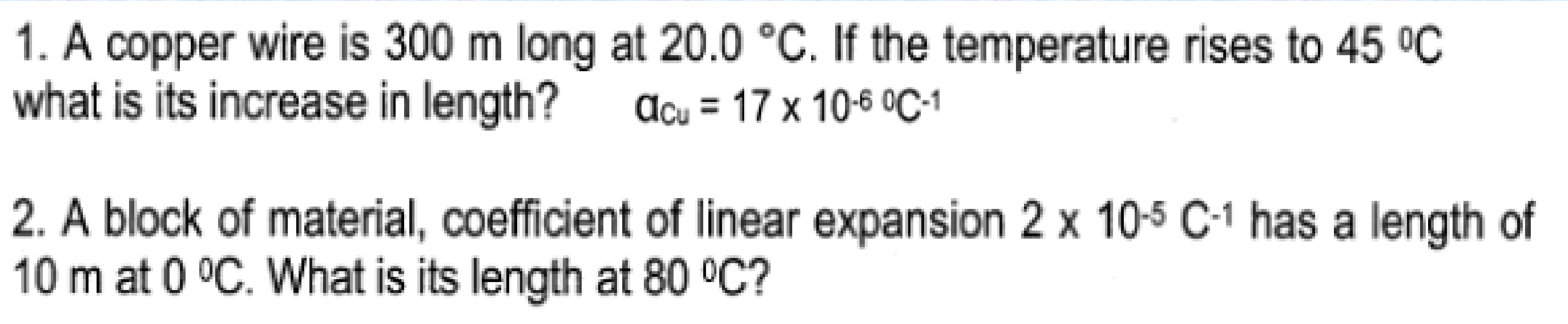
ANSWER $\Delta T = 40 - 25 = 15^\circ c$

$$L_{40^\circ c} = L_0(1 + \alpha \Delta T)$$
$$= 1150(1 + 11 \times 10^{-6} \times 15)$$
$$= 1150(1 + 1.65 \times 10^{-4}$$
$$= 1150.19\ m$$

It EXPANDS BY 20cm

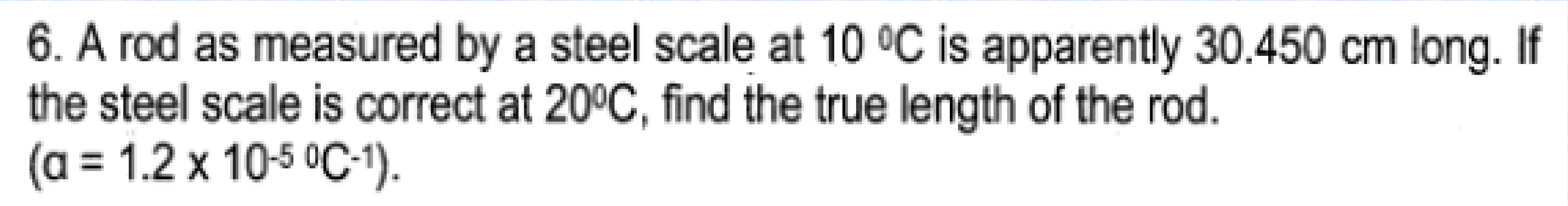
$$\boxed{\Delta L = \alpha L_0 \Delta T}$$

Expansion of Length – Student Problems

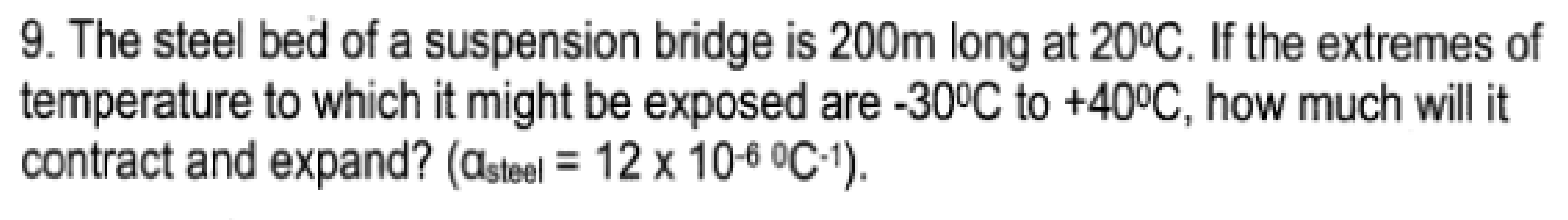


1. A copper wire is 300 m long at 20.0 °C. If the temperature rises to 45 ^{0}C what is its increase in length? $\alpha_{Cu} = 17 \times 10^{-6}\ ^0C^{-1}$

2. A block of material, coefficient of linear expansion 2×10^{-5} C^{-1} has a length of 10 m at 0 ^{0}C. What is its length at 80 ^{0}C?



6. A rod as measured by a steel scale at 10 ^{0}C is apparently 30.450 cm long. If the steel scale is correct at 20^{0}C, find the true length of the rod. ($\alpha = 1.2 \times 10^{-5}\ ^0C^{-1}$).



9. The steel bed of a suspension bridge is 200m long at 20^{0}C. If the extremes of temperature to which it might be exposed are -30^{0}C to +40^{0}C, how much will it contract and expand? ($\alpha_{steel} = 12 \times 10^{-6}\ ^0C^{-1}$).

Thermal Expansion

Q1 $L = 300\,m \quad \Delta T = 45 - 20 = 25^\circ c$

$\Delta L = \alpha L_o \Delta T = 17\times10^{-6} \times 300 \times 25 = \boxed{0.127\,m}$

Q2 $\alpha_M = 2\times10^{-5}$; $L = 10\,m$; $\Delta T = 80^\circ$

$\therefore$ ~~NEW~~ $\Delta L = \alpha L_o \Delta T = 0.016\,m$

$\therefore$ NEW LENGTH $= L + \Delta L = \boxed{10.016\,m}$

Q3 KEEP BALL AT SOME CONSTANT ROOM TEMPERATURE (25°c)

INCREASE TEMPERATURE OF HOLE → INCREASE DIAMETER OF HOLE → TO NEW TEMPERATURE: T_F

$\Rightarrow \Delta L_{(HOLE)} = 4{\cdot}0\,cm - 2\times1.995\,cm = 4{\cdot}0 - 3{\cdot}99$

$= \cancel{0.001} = 0.01\,cm$

NOW $\Delta L = \alpha L_o \Delta T$

SO $\Delta T = \dfrac{\Delta L}{\alpha L_o} = \dfrac{0.01\,cm \times 1\times10^{-2}}{2\times10^{-5} \times 1.995\times10^{-2}}$

$= 250.62^\circ$

SO MUST RAISE TEMPERATURE OF HOLE BY $250.62 - 25^\circ = \boxed{225^\circ C}$

Q4 $\Delta L = \alpha L_o \Delta T$

$= 0.000012 \times$! !

(SILLY QUESTION)

HOW CAN THE GOLDEN GATE BRIDGE BE ONLY 1.25 mm LONG ??

(Golden Gate Bridge is actually about 2870 metres in length !)

Q4 $L_o = 2870$

$\Delta T = 36^\circ - 6^\circ = 30^\circ c$

$\alpha = 0.000012$

$\Delta L = L_o \alpha \Delta T$

$= 2870 \times 30^\circ \times 0.000012$

$= 1.0332\,m$

Thermal Expansion (Continued..)

$\boxed{Q5}$ LENGTH:

$\Delta L = L_0 \alpha \Delta T = 19 \times 10^{-6} \times 0.02 \times 60$

$= 2.28 \times 10^{-5}$

$\therefore$ NEW EDGE LENGTH $= L + \Delta L = \boxed{2.00228 \times 10^{-2} m}$

VOLUME

$V_{INITIAL} = 0.02 \times 0.02 \times 0.02 = 8 \times 10^{-6} m^3$

$\Delta V = \beta V_0 \Delta T = 3 \times 19 \times 10^{-6} \times 8 \times 10^{-6} \times 60$

$= 2.736 \times 10^{-8}$

$\therefore$ NEW VOLUME $= V + \Delta V = \boxed{8.02736 \times 10^{-6} m^3}$

DENSITY:

Density $= \rho = \frac{MASS}{VOLUME}$

MASS WILL NOT CHANGE!

SO NEW DENSITY $= \frac{0.068}{8.02736 \times 10^{-6} m^3}$

$= \boxed{8.471 \times 10^3 kg m^3}$

$\alpha = 1.2 \times 10^{-5}$ $\Delta T = 10$

$\boxed{Q6}$ FIND ΔL $L = 30.45 cm$

$= 0.3045 m$

$\Delta L = \alpha L_0 \Delta T$

~~$= 30.45 \times 10 \times 1.2 \times 10^{-5} \times 0.1$~~

$= 1.2 \times 10^{-5} \times 0.3045 \times 10$

$= 3.654 \times 10^{-5} m$

NOW: STEEL RULE IS CORRECT AT 20° C NOT 10°C

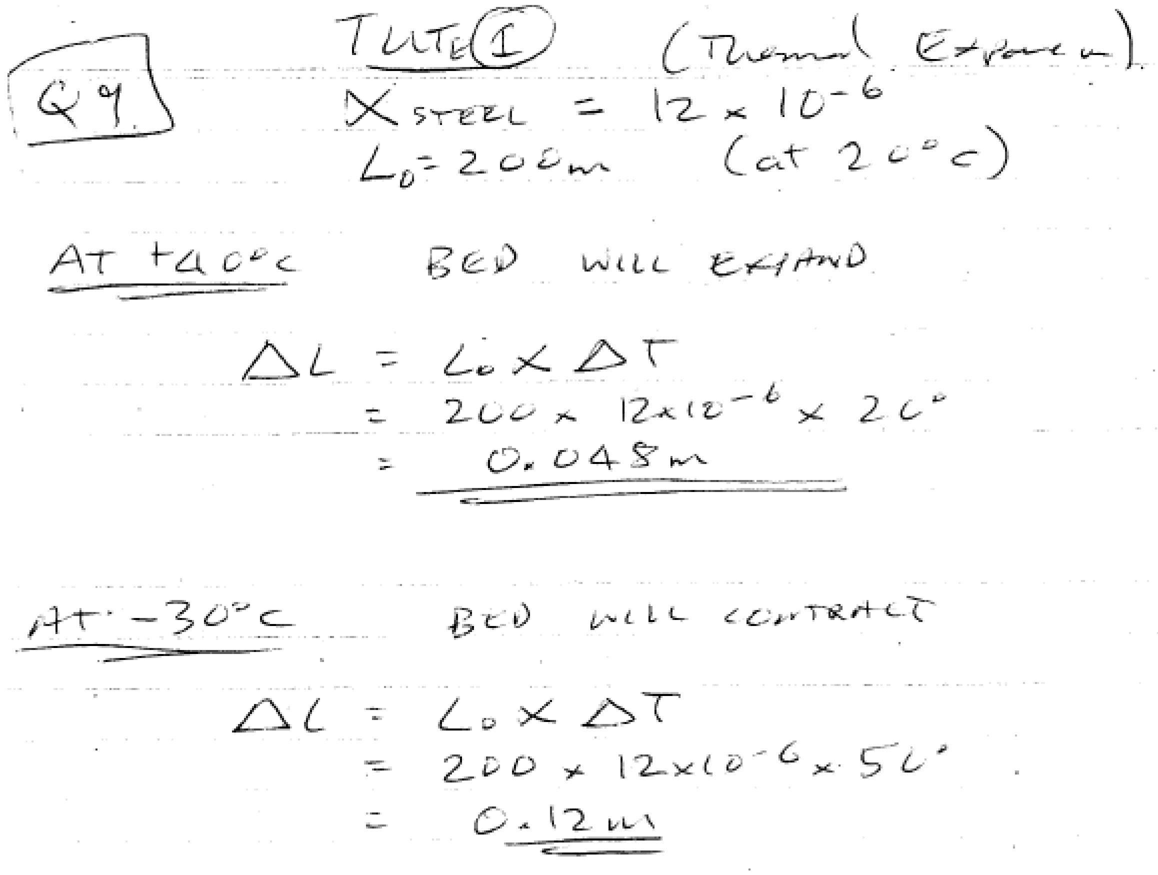
SO; ROD IS ACTUALLY SHORTER BY ΔL

$\therefore$ TRUE ROD LENGTH =

$\Rightarrow 3.045 \times 10^{-1} - 3.654 \times 10^{-5}$

$\Rightarrow 30.446 cm$

Thermal Expansion (Continued..)



Q4.

TUTE ① (Thermal Expansion)

$\alpha_{STEEL} = 12 \times 10^{-6}$

$L_0 = 200m$ (at 20°C)

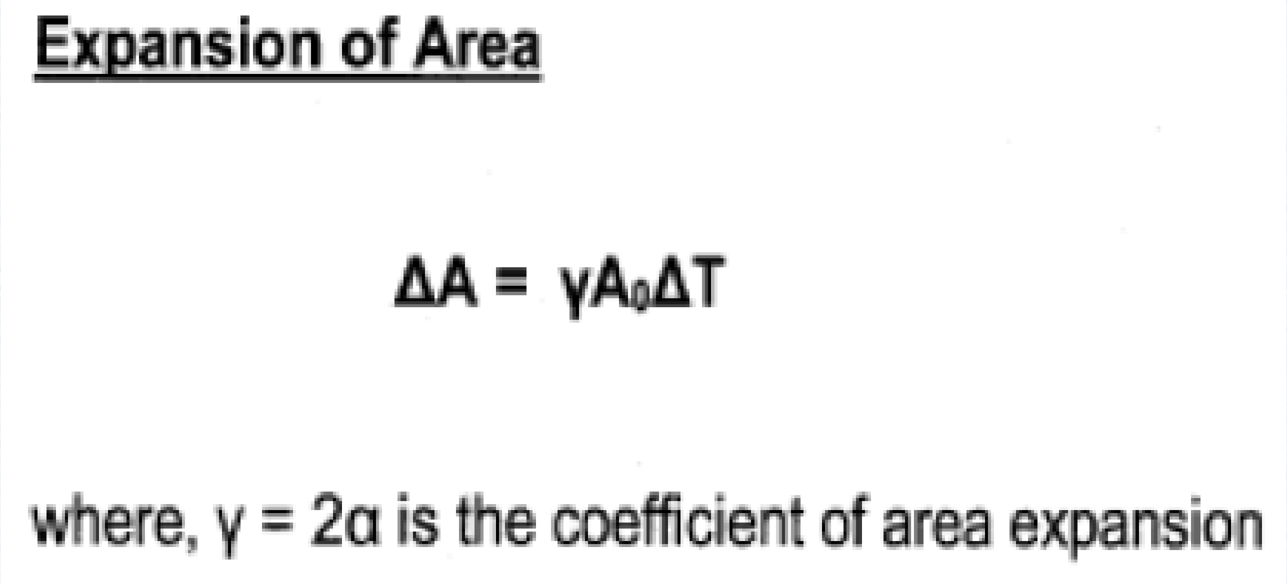
AT +40°C BED WILL EXPAND

$$\Delta L = L_0 \alpha \Delta T$$
$$= 200 \times 12 \times 10^{-6} \times 20°$$
$$= \underline{\underline{0.048m}}$$

AT -30°C BED WILL CONTRACT

$$\Delta L = L_0 \alpha \Delta T$$
$$= 200 \times 12 \times 10^{-6} \times 50°$$
$$= \underline{\underline{0.12m}}$$

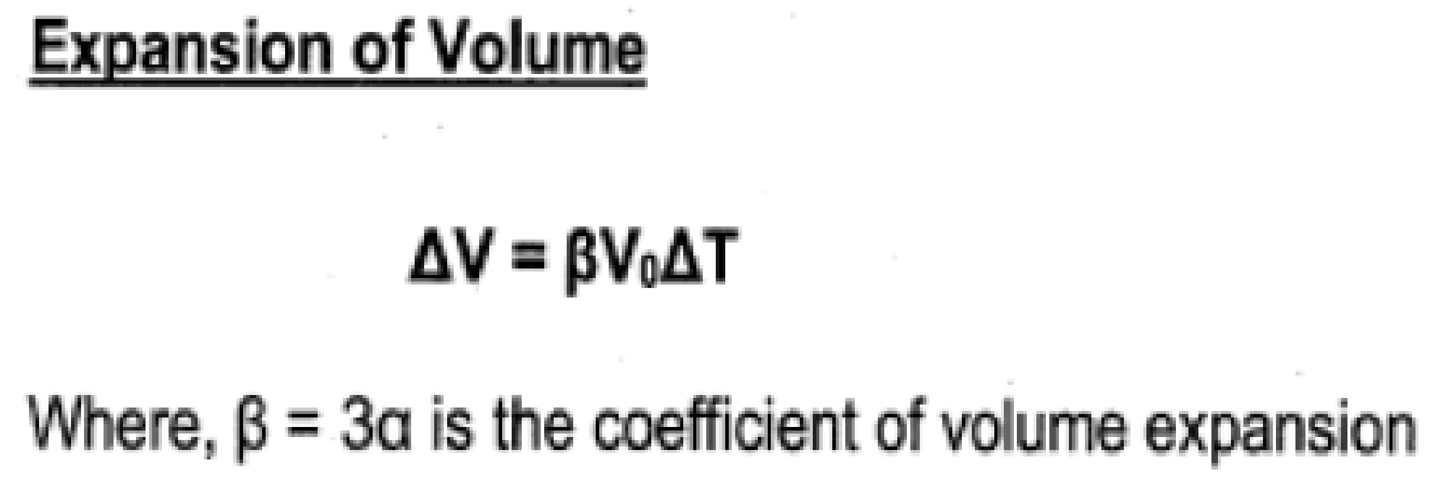
Expansion of Area and Volume



Expansion of Area

$$\Delta A = \gamma A_0 \Delta T$$

where, $\gamma = 2\alpha$ is the coefficient of area expansion



Expansion of Volume

$$\Delta V = \beta V_0 \Delta T$$

Where, $\beta = 3\alpha$ is the coefficient of volume expansion

VOLUME EXPANSION:

SOLIDS $\Delta V = V_0 \times 3 \times \alpha \times \Delta T$

LIQUID $\Delta V = V_0 \times \beta \times \Delta T$

AREA EXAMPLE

A CIRCULA COPPER PLATE OF DIAMETER 0.6m IS AT TEMPERATURE OF 20°C. WHAT IS AREA OF PLATE AT 85°C

$(\alpha_{Cu} = 17\times10^{-6}\,C^{\circ})$

$(\Delta A = 2 \times \alpha \times A \times \Delta T)$

ANSWER:

① FIND INITIAL AREA: $A = \pi r^2$

$= \frac{\pi D^2}{4}$

$= 0.2827\,m^2$

② FIND ΔA

$\Delta A = 2\alpha A \times \Delta T$

$= 2 \times 17 \times 10^{-6} \times 0.2827$

$\approx 6.24767\times10^{-4}$ $\times 65$

③ NOW FIND FINAL AREA.

NEW $A = A_i + \Delta A$

$= 0.2827\,m^2 + 6.2476\times10^{-4}$

$= 0.2833\,m^2$

Sample Problem 19-2

On a hot day in Las Vegas, an oil trucker loaded 37,000 L of diesel fuel. He encountered cold weather on the way to Payson, Utah, where the temperature was 23.0 K lower than in Las Vegas, and where he delivered his entire load. How many liters did he deliver? The coefficient of volume expansion for diesel fuel is $9.50 \times 10^{-4}/\mathrm{C}^{\circ}$, and the coefficient of linear expansion for his steel truck tank is $11 \times 10^{-6}/\mathrm{C}^{\circ}$.

SOLUTION: The Key Idea here is that the volume of the diesel fuel depends directly on the temperature. Thus, because the temperature decreased, the volume of the fuel did also. From Eq. 19-10, the volume change is

$$\begin{aligned}\Delta V &= V\beta\,\Delta T\\ &= (37{,}000\ \mathrm{L})(9.50 \times 10^{-4}/\mathrm{C}^{\circ})(-23.0\ \mathrm{K}) = -808\ \mathrm{L}.\end{aligned}$$

Thus, the amount delivered was

$$\begin{aligned}V_{\mathrm{del}} &= V + \Delta V = 37{,}000\ \mathrm{L} - 808\ \mathrm{L}\\ &= 36{,}190\ \mathrm{L}. \qquad \text{(Answer)}\end{aligned}$$

Note that the thermal expansion of the steel tank has nothing to do with the problem. Question: Who paid for the "missing" diesel fuel?

Consider this problem...

I FILL UP MY 50,000 LITRES TANKER AT \$1 PER LITRE IN MORNING WHEN TEMP = 4°C

I SELL ALL MY FUEL AT TEMP = 34°C AT \$1 PER LITRE !

DO I LOSE OR GAIN?
HOW MUCH IN \$\$?

Formulas

$$\beta_o = 9.5 \times 10^{-4}$$

$$\Delta V = \beta V_0 \times \Delta T$$

I FILL UP MY TANKER
50,000 LITRES
AT $1 PER LITRE
IN MORNING WHEN TEMP = 4°C
I SELL ALL MY FUEL AT
TEMP = 34°C AT $1 PER
LITRE ! (BIT OF A GOOSE !)
DO I LOSE OR GAIN?
HOW MUCH IN $$?

$$\beta_0 = 9.5 \times 10^{-4}$$

$$\Delta V = \beta V_0 \times \Delta T$$

$$\Delta V = 9.5 \times 10^{-4} \times 50{,}000 \times 30$$
$$= 1425 \text{ Litres}$$

SO: I MAKE AN EXTRA
$1425 PROFIT
BY RESULT OF EXPANSION
EXCELLENT IDEA !

Area and Volume – Student Problems

5. The edge of a brass cube of mass 0.068 kg is 0.02 m at 0 °C. What are its length of edge, volume, and density when its temperature is 60 ^0C?

$\alpha_{brass} = 19 \times 10^{-6}\ {}^0C^{-1}$

8. The density of water at 4^0C is 1.00 x 10^3 kgm^{-3}. What is water's density at 94^0C?

$\beta water = 2\ X\ 10^{-4}\ {}^0C^{-1}$

Thermal Expansion (Continued..)

$\boxed{\text{Q5}}$ LENGTH:

$\Delta L = L_0 \alpha \Delta T = 19 \times 10^{-6} \times 0.02 \times 60$

$= 2.28 \times 10^{-5}$

$\therefore$ NEW EDGE LENGTH $= L + \Delta L = \boxed{2.00228 \times 10^{-2}\,m}$

VOLUME

$V_{\text{INITIAL}} = 0.02 \times 0.02 \times 0.02 = 8 \times 10^{-6}\,m^3$

$\Delta V = \beta V_0 \Delta T = 3 \times 19 \times 10^{-6} \times 8 \times 10^{-6} \times 60$

$= 2.736 \times 10^{-8}$

$\therefore$ NEW VOLUME $= V + \Delta V = \boxed{8.02736 \times 10^{-6}\,m^3}$

DENSITY:

Density $= \rho = \dfrac{\text{MASS}}{\text{VOLUME}}$

MASS WILL NOT CHANGE!

SO NEW DENSITY $= \dfrac{0.068}{8.02736 \times 10^{-6}\,m^3}$

$= \boxed{8.471 \times 10^3\,kg\,m^3}$

$\alpha = 1.2 \times 10^{-5} \qquad \Delta T = 10$

$\boxed{\text{Q6}}$ FIND ΔL $\qquad L = 30.45\,cm$

$= 0.3045\,m$

$\Delta L = \alpha L_0 \Delta T$

~~$= 30.45 \times 10 \times 1.2 \times 10^{-5} \times 0.1$~~

$= 1.2 \times 10^{-5} \times 0.3045 \times 10$

$= 3.654 \times 10^{-5}\,m$

NOW: STEEL RULE IS CORRECT AT 20° C NOT 10°C

SO; ROD IS ACTUALLY SHORTER by ΔL

$\therefore$ TRUE ROD LENGTH =

$\Rightarrow 3.045 \times 10^{-1} - 3.654 \times 10^{-5}$

$\Rightarrow$ 30.446 cm

Thermal Expansion (Continued..)

Q7

$\alpha_{glass} = 8.5 \times 10^{-6}$

$\beta_{WATER} = 2.00 \times 10^{-4}$

(100 cc = 100 ml)

$\beta = 3\alpha$

$\Delta T = 60^\circ$

Bottle

$\Delta V_b = V_0 \beta \Delta T$

$= 100 \times 3 \times 8.5 \times 10^{-6} \times 60$

$= \underline{0.153}$ ml

$\Delta V_{WATER} = V_0 \beta \Delta T$

$= 100 \times \cancel{3} \times 2 \times 10^{-4} \times 60$

$= \underline{1.2}$ ml

Spillage = $\Delta V_w - \Delta V_b$

$= 1.2 - 0.153 = \underline{1.047\text{ ml}}$

Q8

DENSITY = $\rho = \dfrac{\text{MASS}}{\text{VOLUME}}$

$1\text{ m}^3 = 1.0 \times 10^6$ ml

$\Delta V = \beta V_0 \Delta T = 2 \times 10^{-4} \times 90^\circ \times 1.0 \times 10^6$ ml

$= 18{,}000$ ml

$V + \Delta V = 1.018 \times 10^6\text{ ml} = 1.018\text{ m}^3$

NEW DENSITY $= \dfrac{1}{1.018} = \underline{0.982 \times 10^3\text{ kg m}^{-3}}$

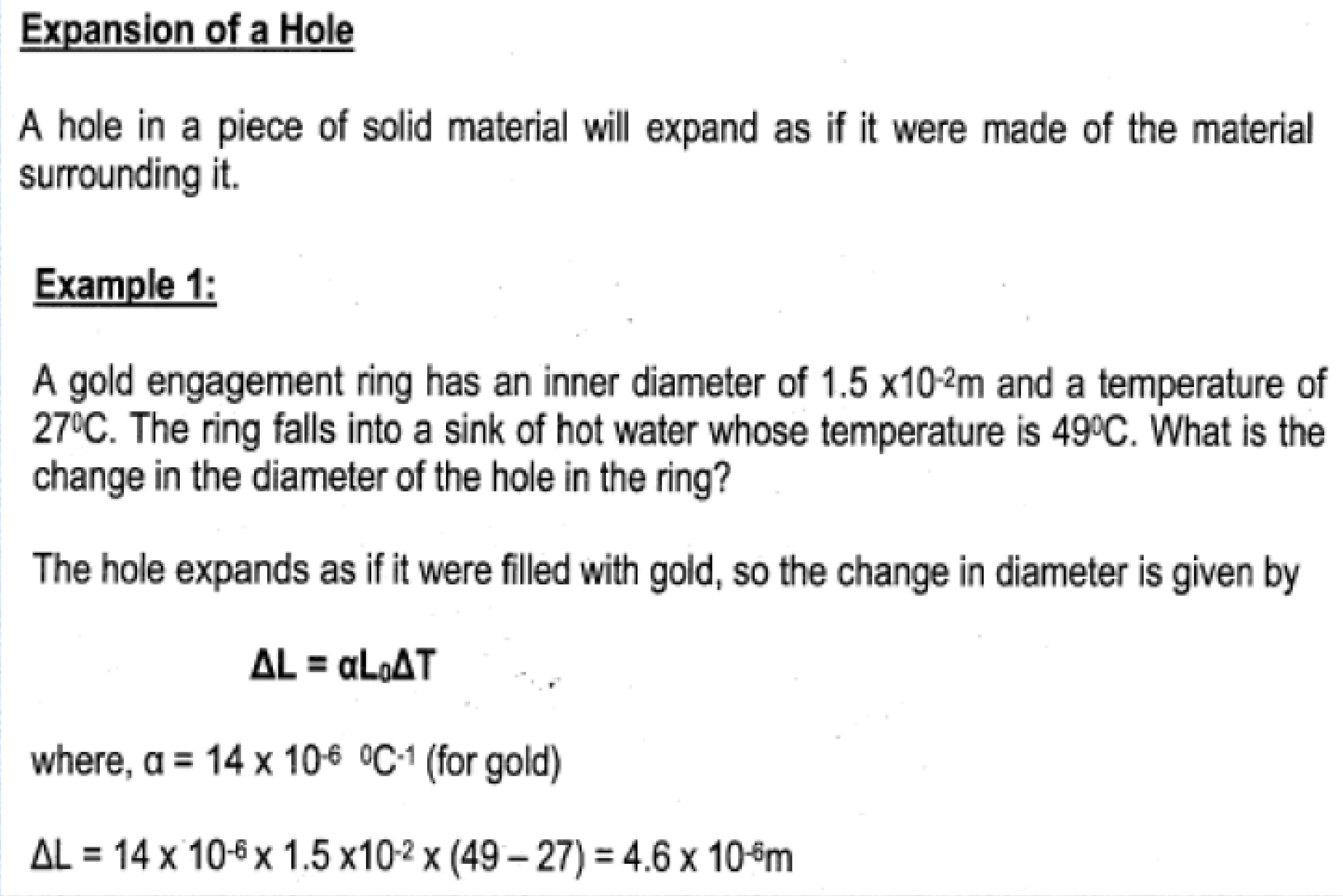
$\Delta T = T_f - T_i$

$= 94 - 4 = \underline{90^\circ}$

$1.0 \times 10^6 + 18{,}000$ $\quad 0.18 \times 10$ $\quad 0.018 \times 10^6$

$= 1.0 \times 10^6 + 1.8 \times 10^4 = 1.018 \times 10^6$

Expansion of a Hole



Expansion of a Hole

A hole in a piece of solid material will expand as if it were made of the material surrounding it.

Example 1:

A gold engagement ring has an inner diameter of 1.5×10^{-2}m and a temperature of 27^0C. The ring falls into a sink of hot water whose temperature is 49^0C. What is the change in the diameter of the hole in the ring?

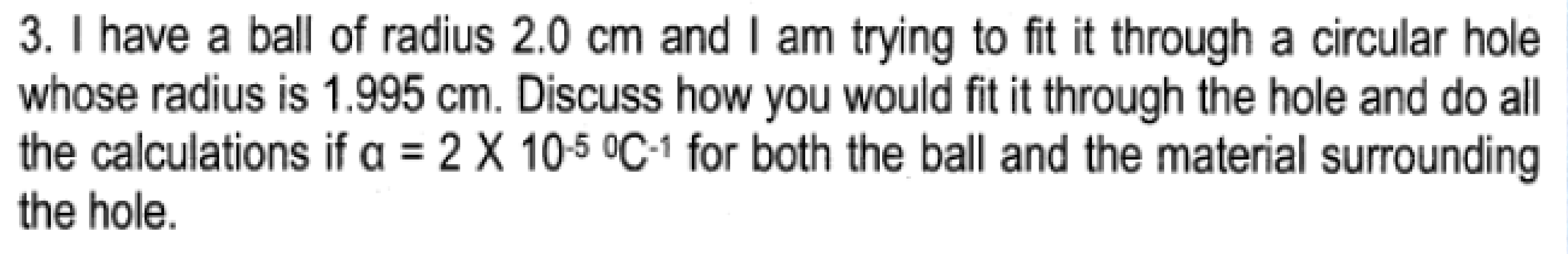
The hole expands as if it were filled with gold, so the change in diameter is given by

$$\Delta L = \alpha L_0 \Delta T$$

where, $\alpha = 14 \times 10^{-6}\ {}^0C^{-1}$ (for gold)

$\Delta L = 14 \times 10^{-6} \times 1.5 \times 10^{-2} \times (49 - 27) = 4.6 \times 10^{-6}$m

Expansion of a Hole – Student Problem



3. I have a ball of radius 2.0 cm and I am trying to fit it through a circular hole whose radius is 1.995 cm. Discuss how you would fit it through the hole and do all the calculations if α = 2 X 10^{-5} $^{0}C^{-1}$ for both the ball and the material surrounding the hole.

Thermal Expansion

Q1 $L = 300m \quad \Delta T = 45 - 20 = 25°c$

$\Delta L = \alpha L_o \Delta T = 17\times10^{-6} \times 300\times25 = \boxed{0.127m}$

Q2 $\alpha_M = 2\times10^{-5}$; $L = 10m$; $\Delta T = 80°$

∴ ~~NEW~~ $\Delta L = \alpha \cancel{M} L_o \Delta T = 0.016m$

∴ NEW LENGTH $= L + \Delta L = \boxed{10.016m}$

Q3 KEEP BALL AT SOME CONSTANT ROOM TEMPERATURE (25°c)

INCREASE TEMPERATURE OF HOLE → INCREASE DIAMETER OF HOLE → TO NEW TEMPERATURE: T_F

$\Rightarrow \Delta L_{(HOLE)} = 4.0cm - 2\times1.995cm = 4.0 - 3.99$

$= \cancel{0.001} = 0.01cm$

NOW $\Delta L = \alpha L_o \Delta T$

SO $\Delta T = \dfrac{\Delta L}{\alpha L_o} = \dfrac{0.01cm \times 1\times10^{-2}}{2\times10^{-5} \times 1.995\times10^{-2}}$

$= 250.62°$

SO MUST RAISE TEMPERATURE OF HOLE BY $250.62 - 25° = \boxed{225°C}$

Q4 $\Delta L = \alpha L_o \Delta T$

$= 0.000012 \times$! !

(SILLY QUESTION)

HOW CAN THE GOLDEN GATE BRIDGE BE ONLY 1.25 mm LONG ??

(Golden Gate Bridge is actually about 2870 metres in length !)

Q4 $L_o = 2870$

$\Delta T = 36° - 6° = 30°c$

$\alpha = 0.000012$

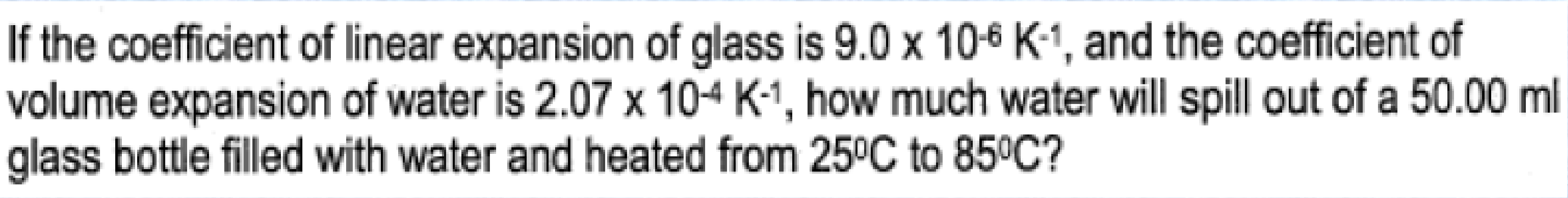
$\Delta L = L_o \alpha \Delta T$

$= 2870 \times 30° \times 0.000012$

$= 1.0332\ m$

Expansion of composite materials

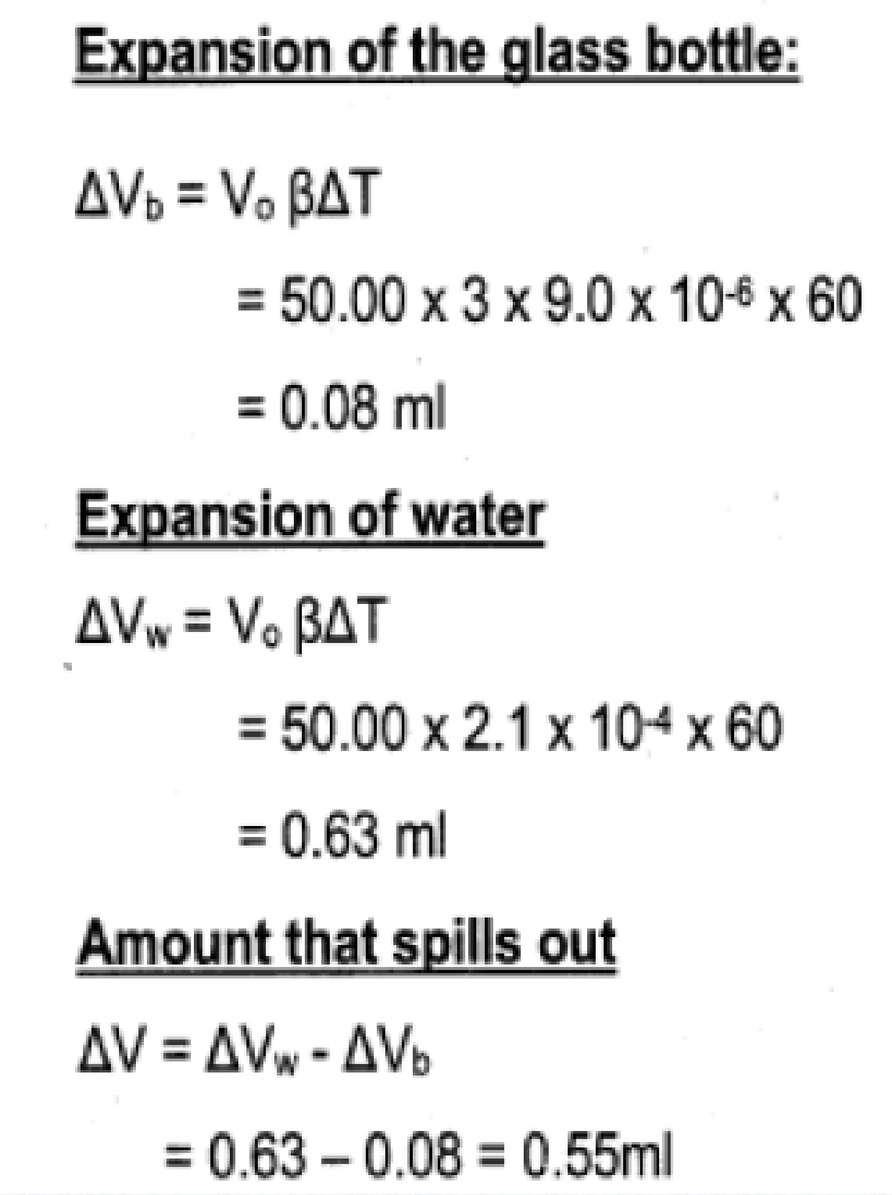
Consider this problem…



If the coefficient of linear expansion of glass is 9.0×10^{-6} K^{-1}, and the coefficient of volume expansion of water is 2.07×10^{-4} K^{-1}, how much water will spill out of a 50.00 ml glass bottle filled with water and heated from 25^0C to 85^0C?

To solve this:

1. Calculate the volume expansion of the glass bottle (remember to use $\beta_{glass} = 3\alpha_{glass}$!!).
2. Calculate the volume expansion of the water.
3. Subtract the answers for parts 1 and 2



Expansion of the glass bottle:

$\Delta V_b = V_o \beta \Delta T$

$= 50.00 \times 3 \times 9.0 \times 10^{-6} \times 60$

$= 0.08$ ml

Expansion of water

$\Delta V_w = V_o \beta \Delta T$

$= 50.00 \times 2.1 \times 10^{-4} \times 60$

$= 0.63$ ml

Amount that spills out

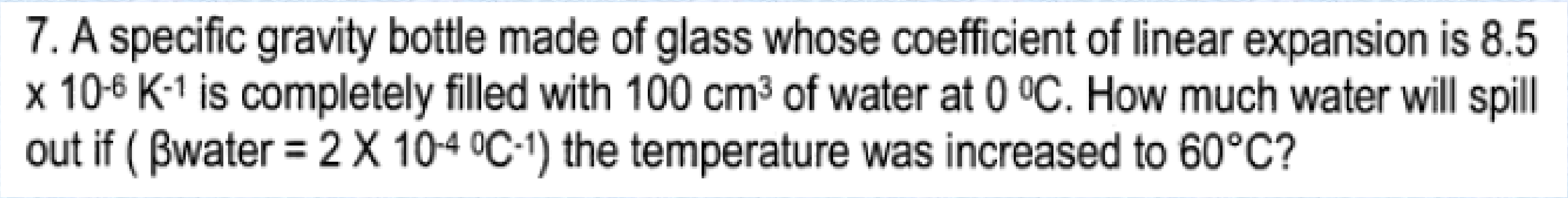
$\Delta V = \Delta V_w - \Delta V_b$

$= 0.63 - 0.08 = 0.55$ml

Did you get the right answer ?

Did you get the right answer to the previous problem?

If not, then try this problem as revision …



7. A specific gravity bottle made of glass whose coefficient of linear expansion is 8.5 x 10^{-6} K^{-1} is completely filled with 100 cm^3 of water at 0 ^0C. How much water will spill out if ($\beta_{water} = 2 \times 10^{-4}$ $^0C^{-1}$) the temperature was increased to 60°C?

VOLUME ~~X~~EXPANSION:

(NOTES EXAMPLE 2)

GLASS (SOLIDS)

$\Delta V = 3 \times \alpha V \times \Delta T$

(GLASS BOTTLE)

FLUIDS: (WATER)

$\Delta V = \beta \times V \times \Delta T$

Thermal Expansion (Continued..)

$\boxed{Q7}$ $\beta_{glass} = 8.5\times10^{-6}$

$\beta_{WATER} = 2.00\times10^{-4}$

$(100cc = 100ml)$

$\Delta T = 60^\circ$

$\beta = 3\alpha$

Bottle

$$\Delta V_b = V_o \beta \Delta T$$
$$= 100 \times 3 \times 8.5\times10^{-6} \times 60$$
$$= \underline{\underline{0.153}}\ ml$$

$$\Delta V_{WATER} = V_o \beta \Delta T$$
$$= 100 \times \cancel{3} \times 2\times10^{-4} \times 60$$
$$= \underline{\underline{1.2}}\ ml$$

$$\text{Spillage} = \Delta V_w - \Delta V_b$$
$$= 1.2 - 0.153 = \underline{\underline{1.047ml}}$$

$\boxed{Q8}$ $\text{DENSITY} = \rho = \frac{\text{MASS}}{\text{VOLUME}}$

$$1m^3 = 1.0\times10^6 ml$$

$$\Delta V = \beta V_o \Delta T = 2\times10^{-4} \times 90^\circ \times 1.0\times10^6\ ml$$
$$= 18{,}000\ \underline{ml}$$

$$V + \Delta V = 1.018\times10^6\ ml = 1.018\ m^3$$

$$\text{NEW DENSITY} = \frac{1}{1.018} = \underline{\underline{0.982\times10^3\ kgm^{-3}}}$$

$$\Delta T = T_f - T_i$$
$$= 94 - 4 = \underline{\underline{90}}^\circ$$

$1.0\times10^6 + 18{,}000.$ 0.18×10^6 0.018×10^6

$= 1.0\times10^6 + 1.8\times10^4 = 1.018\times10^6$

Specific Heat Capacity

- The amount of heat required to raise a certain mass of a material by a certain temperature is called heat capacity.

$$Q = mc\Delta T$$

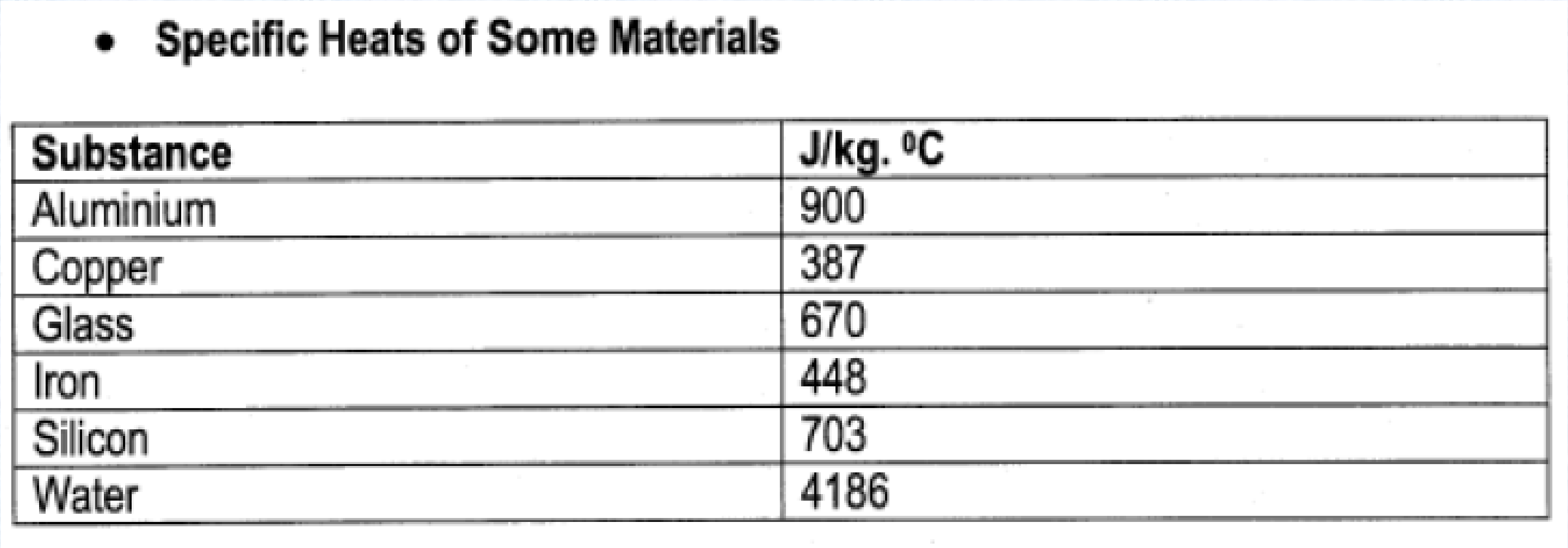
m = mass (Kg)

c = specific heat capacity ($JKg^{-1}°C$)

ΔT = change in temperature

Specific Heat Capacity

- The specific heat capacity is defined as the heat energy required to raise 1Kg of a substance by 1 Celsius degree
- Every substance requires a unique amount of energy per unit mass to change the temperature of that substance by 1 Celsius degree.



- **Specific Heats of Some Materials**

Substance	**J/kg. ^{0}C**
Aluminium	900
Copper	387
Glass	670
Iron	448
Silicon	703
Water	4186

Consider this problem...

HOW LONG DOES IT TAKE
TO USE A 2.5KW KETTLE
TO RAISE 1kgm WATER
FROM 25°C to 100°C (BOILS!)

Formulas

$$Q = mC\Delta T$$

C = HEAT CAPACITY
= 4186 (for water)

m = MASS (kgm)

ΔT = CHANGE IN TEMP

ENERGY = POWER × TIME

$$\text{TIME} = \frac{\text{ENERGY}}{\text{POWER}}$$

HEAT CAPACITY:

$$Q = mC\Delta T$$

↑
HEAT

C = HEAT CAPACITY
m = MASS (kgm)
ΔT = CHANGE IN TEMP

HOW LONG DOES IT TAKE TO USE A 2.5KW KETTLE TO RAISE WATER FROM 25°C TO 100°C (BOILS!)
(FOR 1 Litre = 1 kgm)

$$Q = mC\Delta T$$
$$= 1 \times 4186 \times (100-25)$$
$$= 313{,}950$$

ENEGRY = POWER × TIME

$$\text{TIME} = \frac{\text{ENERGY}}{\text{POWER}} = \frac{313{,}950}{2500}$$
$$= 125 \text{ SECONDS}$$
$$= \underline{2 \text{ minutes}}$$

Specific Heat Capacity

If 25.0 g of Al cool from 310 ^{o}C to 37 ^{o}C, how many joules of heat energy are lost by the Al?

$$\text{Specific heat capacity} = \frac{\text{heat lost or gained by substance}}{(\text{mass, g})(\text{T change,K})}$$

Specific Heat Capacity

If 25.0 g of Al cool from 310 ^oC to 37 ^oC, how many joules of heat energy are lost by the

heat gain/lose = q = (sp. ht.)(mass)(ΔT)

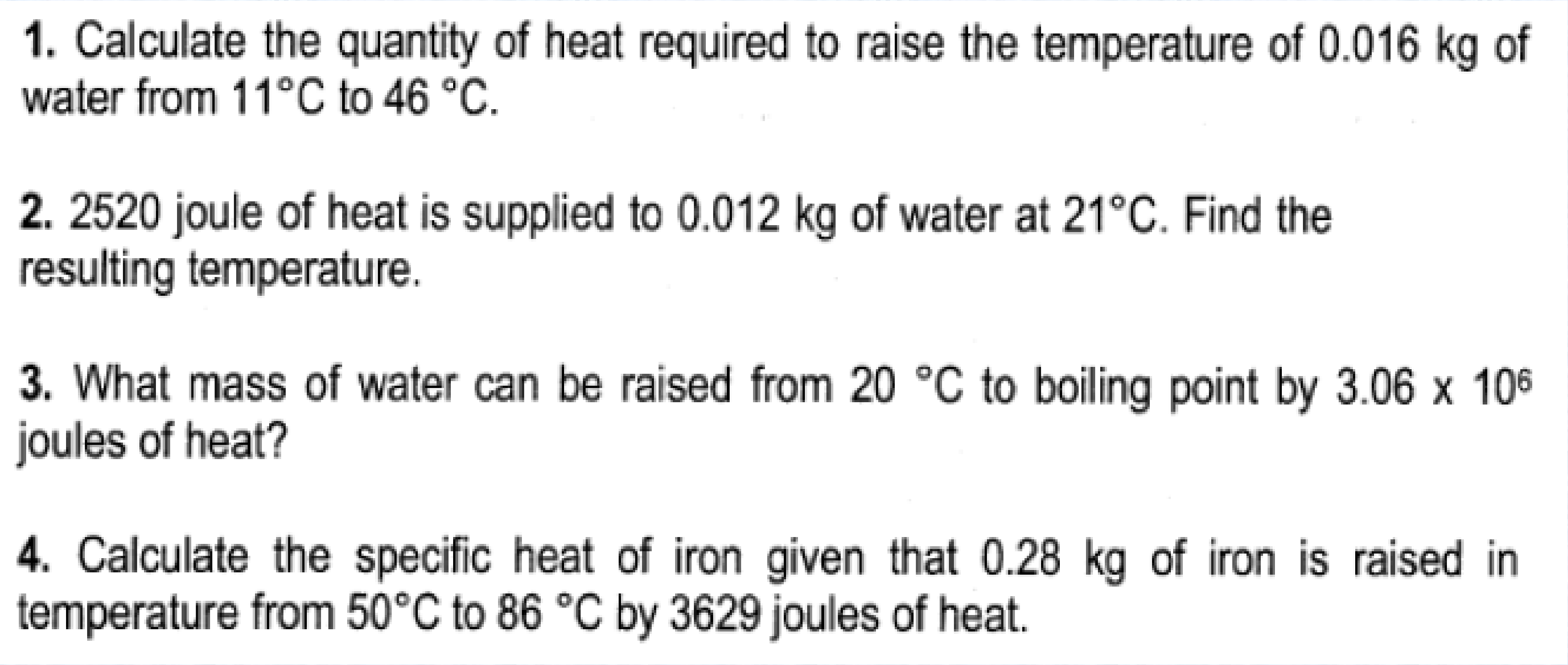
where $\Delta T = T_{final} - T_{initial}$

$q = (0.897\ J/g \bullet K)(25.0\ g)(37 - 310)K$

$q = -\ 6120\ J$

Notice that the negative sign on q signals heat "lost by" or transferred OUT of Al.

Heat Capacity – Student Problems



1. Calculate the quantity of heat required to raise the temperature of 0.016 kg of water from 11°C to 46 °C.

2. 2520 joule of heat is supplied to 0.012 kg of water at 21°C. Find the resulting temperature.

3. What mass of water can be raised from 20 °C to boiling point by 3.06×10^6 joules of heat?

4. Calculate the specific heat of iron given that 0.28 kg of iron is raised in temperature from 50°C to 86 °C by 3629 joules of heat.

(Use Specific Heat Capacity for water = 4200 $Jkg^{-1}K^{-1}$)

Heat Capacity and Specific Heat

Q1 $Q = mc\Delta T$ $\quad \Delta T = 46 - 11 = 35°c$

$m = 0.016\ kg$

$\therefore Q = 35 \times 0.016 \times 4186$ $\quad c = 4186\ J/kg\ °c$

$= \boxed{2344.16\ J}$

Q2 $Q = 2520\ ,\ m = 0.012,\ T_1 = 21°c$

$\therefore Q = mc\Delta T \Rightarrow \Delta T = \dfrac{Q}{mc} = 50.17°c$

HENCE; FINAL TEMPERATURE $= 21° + 50.17°c$

$\therefore = \boxed{71.2°c}$

Q3 Boiling Point for Water $= 100°c$

$\Delta T = 100 - 20 = 80°c$

$\therefore Q = mc\Delta T$

$\therefore m = \dfrac{Q}{c\Delta T} = \dfrac{3.06 \times 10^6}{4186 \times 80} = \boxed{9.14\ kg}$

Q4 $Q = mc\Delta T$ $\quad m = 0.28\ ;\ \Delta T = 86 - 50$

$Q = 3629$ $\quad = 36°c.$

$\therefore c = \dfrac{Q}{m\Delta T} = \dfrac{3629}{0.28 \times 36} = \boxed{360\ J/kg\ °c}$

Q5 $M_g = 0.07\ ;\ C_g = 670;$

HEAT LOST BY GLASS BEADS = HEAT GAINED BY WATER + BEAKER

$0.07 \times 670 \times (100 - T_f) = 0.05 \times 4200 \times (T_f - 12)$

$+ 0.04 \times 670 \times (T_f - 12)$

$\Rightarrow 4690 - 46.9T_f = 210T_f - 2520 + 26.8T_f - 321.6$

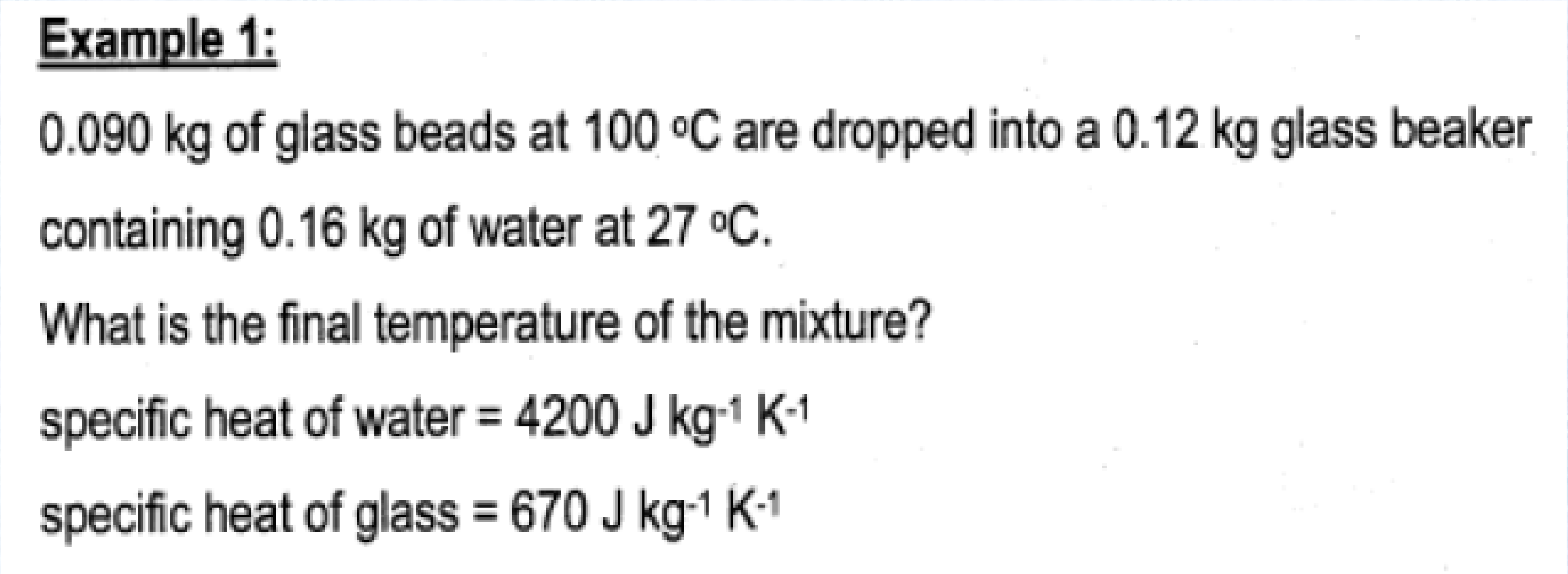
$\Rightarrow 283.7\,T_f = 7531.6$

$\therefore \boxed{T_f = 26.55°C}$

Method of mixtures

In mixtures of substances there will always be conservation of energy in the system so that:

Heat Lost = Heat Gained



Example 1:

0.090 kg of glass beads at 100 ^{o}C are dropped into a 0.12 kg glass beaker containing 0.16 kg of water at 27 ^{o}C.

What is the final temperature of the mixture?

specific heat of water = 4200 J kg^{-1} K^{-1}

specific heat of glass = 670 J kg^{-1} K^{-1}

Heat lost by glass beads = Heat gained by water + beaker

$m_g \times c_g \times \Delta T_g = m_w \times c_w \times \Delta T_w + m_b \times c_g \times \Delta t_b$

$0.09 \times 670 \times (100 - T_f) = 0.16 \times 4200 \times (T_f - 27) + 0.12 \times 670 \times (T_f - 27)$

$6030 - 60.3\,T_f = 672\,T_f - 18144 + 80.4\,T_f - 2171$

$812.7\,T_f = 26345$

$T_f = 32.4\ {}^{o}\mathrm{C}$

METHOD OF MIXTURES

HEAT LOST (COPPER) = HEAT GAINED (WATER)

2 kgw WATER AT 25°C

ADD 0.5kg COPPER AT 125°C

WHAT IS FINAL TEMPERATURE OF WATER.

$$\boxed{Q = mc\Delta T}$$

$$0.5 \times 387 \times (125 - T_f) = 2 \times 4186 \times (t_f - 25)$$

$$24{,}187.5 - 193.5t_f = 8372t_f - 209{,}300$$

$$233{,}487.5 = 8565.5t_f$$

$$t_f = \frac{233{,}487.5}{8565.5t_f}$$

=

$$= \underline{27.26^\circ}$$

DO THIS PROBLEM

1 Kgm IRON AT 100°C

$C_{IRON} = 400$

---

2 Kgm WATER AT 20°C

$C_{WATER} = 4200$

FIND FINAL TEMPERATURE!

ANSWER

HEAT LOST IRON = HEAT GAINED WATER

$$1 \times 400 \times (100 - t_f) = 2 \times 4200 \times (t_f - 20)$$

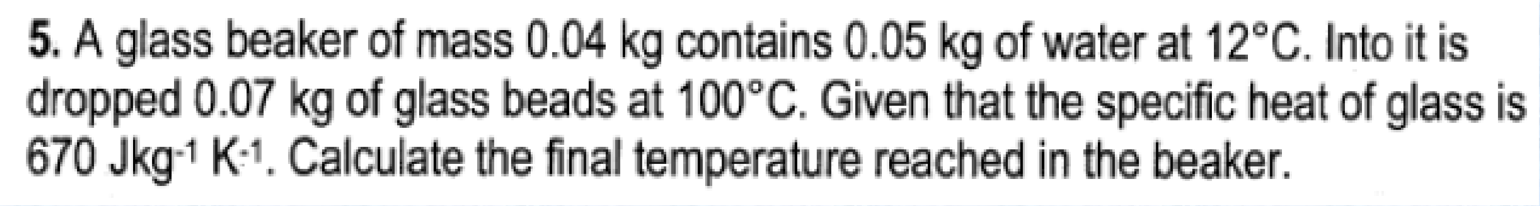
$$40{,}000 - 400t_f = 8400t_f - 168{,}000$$

$$208{,}000 = 8800t_f$$

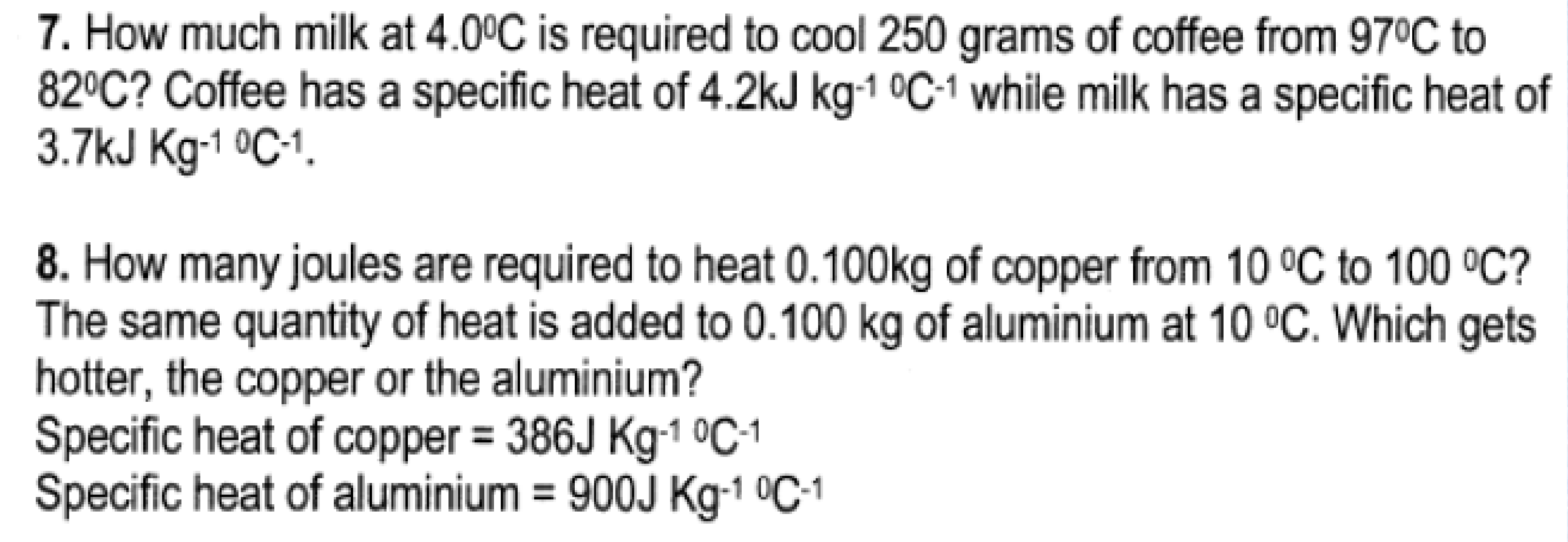
$$\therefore t_f = \frac{208{,}000}{8{,}800}$$

$$= \boxed{23{,}64^\circ}$$

Method of mixtures – Student Problems



5. A glass beaker of mass 0.04 kg contains 0.05 kg of water at 12°C. Into it is dropped 0.07 kg of glass beads at 100°C. Given that the specific heat of glass is 670 Jkg^{-1} K^{-1}. Calculate the final temperature reached in the beaker.



7. How much milk at 4.0^{0}C is required to cool 250 grams of coffee from 97^{0}C to 82^{0}C? Coffee has a specific heat of 4.2kJ kg^{-1} ^{0}C^{-1} while milk has a specific heat of 3.7kJ Kg^{-1} ^{0}C^{-1}.

8. How many joules are required to heat 0.100kg of copper from 10 ^{0}C to 100 ^{0}C? The same quantity of heat is added to 0.100 kg of aluminium at 10 ^{0}C. Which gets hotter, the copper or the aluminium?
Specific heat of copper = 386J Kg^{-1} ^{0}C^{-1}
Specific heat of aluminium = 900J Kg^{-1} ^{0}C^{-1}

Heat Capacity and Specific Heat

$\boxed{Q1}$ $Q = mc\Delta T$ $\Delta T = 46 - 11 = 35°c$

$m = 0.016\ kg$

$c = 4186\ J/kg\ °c$

$\therefore Q = 35 \times 0.016 \times 4186$

$= \boxed{2344.16\ J}$

$\boxed{Q2}$ $Q = 2520$, $m = 0.012$, $T_i = 21°c$

$\therefore Q = mc\Delta T \Rightarrow \Delta T = \frac{Q}{mc} = 50.17°c$

HENCE; FINAL TEMPERATURE $= 21° + 50.17°c$

$\therefore = \boxed{71.2°c}$

$\boxed{Q3}$ Boiling Point for Water $= 100°c$

$\Delta T = 100 - 20 = 80°c$

$\therefore Q = mc\Delta T$

$\therefore m = \frac{Q}{c\Delta T} = \frac{3.06 \times 10^6}{4186 \times 80} = \boxed{9.14\ kg}$

$\boxed{Q4}$ $Q = mc\Delta T$ $m = 0.28$; $\Delta T = 86 - 50$

$Q = 3629$ $= 36°c$

$\therefore c = \frac{Q}{m\Delta T} = \frac{3629}{0.28 \times 36} = \boxed{360\ J/kg\ °c}$

$\boxed{Q5}$ $M_g = 0.07$; $C_g = 670$;

HEAT LOST BY GLASS BEADS = HEAT GAINED BY WATER + BEAKER

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$\Rightarrow 4690 - 46.9T_f = 210T_f - 2520 + 26.8T_f - 321.6$

$\Rightarrow 283.7\ T_f = 7531.6$

$\therefore \boxed{T_f = 26.55°C}$

Heat Capacity and Specific Heat (Continued…)

Q6

HEAT LOST BY COPPER = HEAT GAINED BY ANILINE + CALORIMETER

$$M_{Cu} \times C_{Cu} \times \Delta T_{Cu} = M_A \times C_A \times \Delta T_A + M_{CA} \times C_{CA} \times \Delta T_{CA}$$

$$\Rightarrow 1.1 \times 381 \times (50 - T_f) = 0.3 \times 2100 \times (T_f - 20) + 2.1 \times 381 \times (T_f - 20)$$

$$\Rightarrow 20{,}955 - 419.1 T_f = 630 T_f - 12{,}600 + 800.1 T_f - 16{,}002$$

$$\Rightarrow 1849.2 T_f = 49557$$

$$\Rightarrow \boxed{T_f = 26.8°C}$$

Q7

HEAT LOST BY COFFEE = HEAT GAINED BY MILK

$$m_c \times C_c \times \Delta T_c = M_m \times C_m \times \Delta T_m$$

$$\Rightarrow 0.25 \times 4.2 \times (97 - 82) = M_m \times 3.7 \times (82 - 4)$$

$$\Rightarrow M_m = \frac{0.25 \times 4.2 \times (97 - 82)}{3.7 \times (82 - 4)}$$

$$\boxed{M_m = 0.054\ kg}$$

Q8 $M_c = 0.1\ kg$, $\Delta T = 90°$ $C_{cu} = 3865\ kg^{-1}\ °C^{-1}$

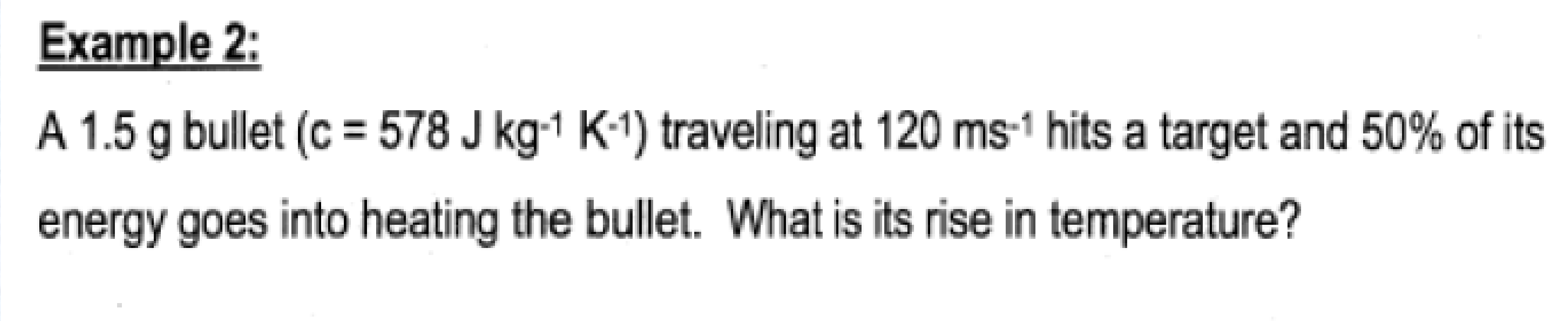
$$Q = MC\Delta T = 0.1 \times 90° \times 386 = \boxed{3474\ J}$$

IF SAME ENERGY APPLIED TO ALUMINIUM;

$Q_A = M_A C_A \Delta T$ $M_A = 0.1$ $C_A = 900\ J\ kg^{-1}\ °C$; $Q_A = 3474$

So $\Delta T = \frac{Q_A}{M_A C_A} = \frac{3474}{0.1 \times 900} = 38.6°$ $\boxed{\text{COPPER GETS HOTTER!}}$

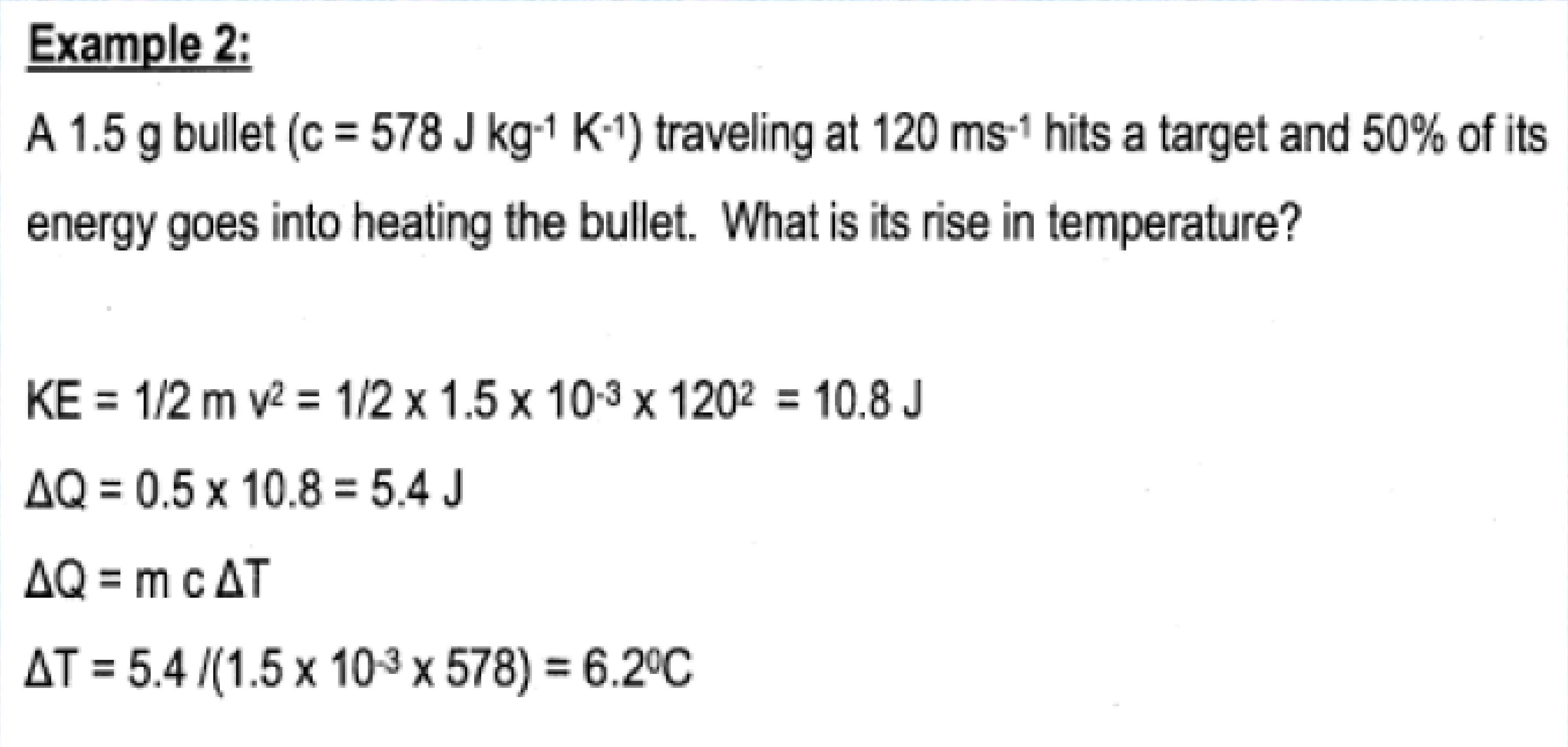
Transfer of Energy Problem



Example 2:

A 1.5 g bullet (c = 578 J kg^{-1} K^{-1}) traveling at 120 ms^{-1} hits a target and 50% of its energy goes into heating the bullet. What is its rise in temperature?

Transfer of Energy Problem



Example 2:

A 1.5 g bullet ($c = 578$ J kg^{-1} K^{-1}) traveling at 120 ms^{-1} hits a target and 50% of its energy goes into heating the bullet. What is its rise in temperature?

$KE = 1/2\ m\ v^2 = 1/2 \times 1.5 \times 10^{-3} \times 120^2 = 10.8$ J

$\Delta Q = 0.5 \times 10.8 = 5.4$ J

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

$\Delta T = 5.4 / (1.5 \times 10^{-3} \times 578) = 6.2^0C$