Boffins Academy

Thermal Physics (Paper I)

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$$P \cdot V = n \cdot R \cdot T \Leftrightarrow$$

Thermal Physics Paper 1

$$P = \frac{n \cdot R}{V} \cdot T \Leftrightarrow$$

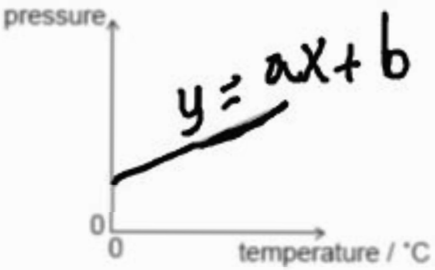
$$P = \frac{m \cdot R}{Mr \cdot V} \cdot T \Leftrightarrow \quad y = a \cdot x$$

1. *[1 mark]*

A fixed mass of an ideal gas is trapped in a cylinder of constant volume and its temperature is varied.

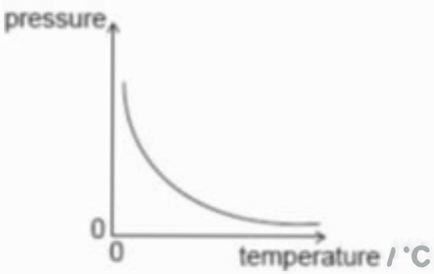
Which graph shows the variation of the pressure of the gas with temperature in degrees Celsius?

A.

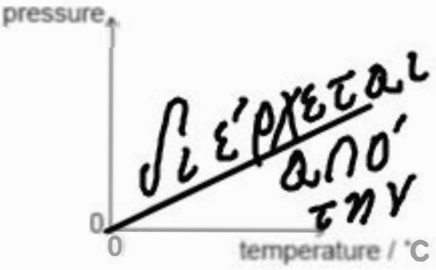


$y = ax + b$

B.



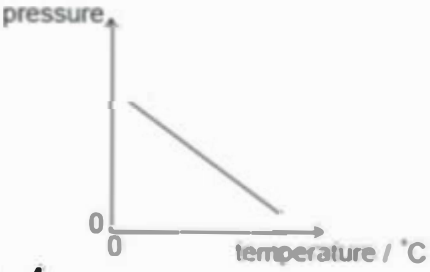
C.



διέρχεται από την

αρχή των αξόνων

D.



2. *[1 mark]*

Latent (Λανθάνουσα)

What are the units of the ratio $\frac{\text{specific heat capacity of copper}}{\text{specific latent heat of vaporization of copper}}$? $= \frac{\frac{\cancel{J}\,1}{\cancel{Kg}\cdot K}}{\frac{\cancel{J}}{\cancel{Kg}}} = K^{-1}$

A. no units

B. k

[✓ C.] k^{-1}

D. k^{-2}

phase: Solid | Gas | Liquid
(στερεό) | (αέριο) | (υγρό)

{ specific heat capacity }
{ ειδική θερμοχωρητικότητα }

3. *[1 mark]*

Specific Latent Heat: Ειδική Λανθάνουσα

Θερμότητα: $\frac{J}{Kg}$

Το ποσό ενέργειας που απαιτείται ανά κιλό (του σώματος για το οποίο μιλάμε), έτσι ώστε να αλλάξει η φάση του, χωρίς να έχουμε μεταβολή της θερμοκρασίας.

Q = Energy/heat.

m = Mass.

c = Specific heat capacity.

T = Temperature.

L = Specific latent heat.

Sub-topic 3.1 – Thermal concepts

$Q = mc\Delta T$	Energy/heat given/received in changing an object's temperature.
$Q = mL$	Energy/heat given/received in changing an object's phase.

$$c = \frac{Q}{m\cdot\Delta T}\left(\frac{J}{Kg\cdot K}\right)$$

$$L = \frac{J}{Kg}$$

T = Period.

f = Frequency.

Sub-topic 4.1 – Oscillations

$T = \frac{1}{f}$	Period (time taken to complete 1 oscillation).

c = Velocity.

f = Frequency.

λ = Wavelength.

Sub-topic 4.2 – Travelling waves

$c = f\lambda$	Speed of a wave.

I = Intensity.

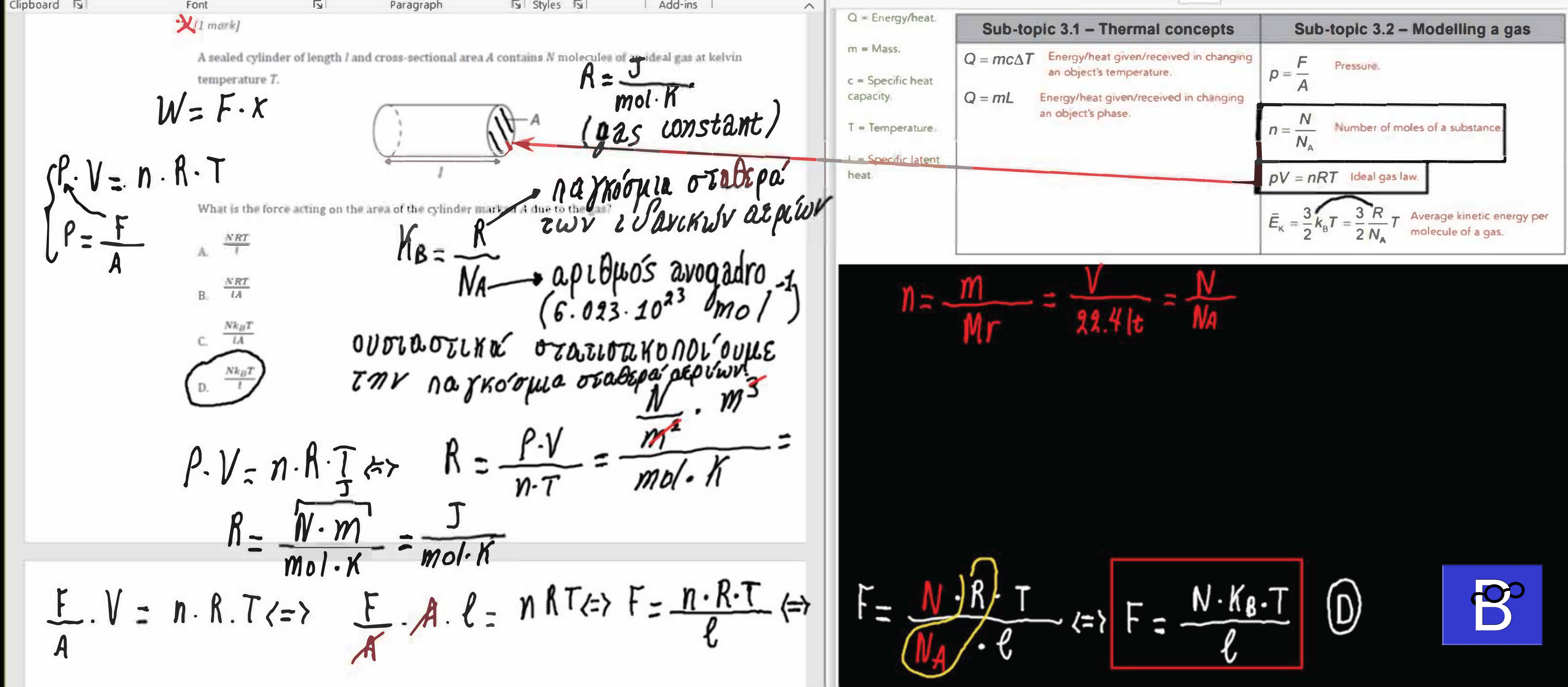
A = Amplitude.

x = Distance from source.

I0 = Original

Sub-topic 4.3 – Wave characteristics

$I \propto A^2$	Intensity of a wave vs. amplitude.
$I \propto x^{-2}$	Intensity of a wave's radiation at a certain distance from the source.
$I = I_0 \cos^2\theta$	Transmitted intensity of light incident on a polariser (Malus's law).



[1 mark]

A sealed cylinder of length *l* and cross-sectional area *A* contains *N* molecules of an ideal gas at kelvin temperature *T*.

What is the force acting on the area of the cylinder marked A due to the gas?

A. $\frac{NRT}{l}$

B. $\frac{NRT}{lA}$

C. $\frac{Nk_BT}{lA}$

[✓ D. $\frac{Nk_BT}{l}$]

$$W = F \cdot x$$

$$\begin{cases} P \cdot V = n \cdot R \cdot T \\ P = \frac{F}{A} \end{cases}$$

$$R = \frac{J}{mol \cdot K}$$

(gas constant)

$$K_B = \frac{R}{N_A}$$

R → παγκόσμια σταθερά των ιδανικών αερίων

N_A → αριθμός avogadro ($6.023 \cdot 10^{23}\ mol^{-1}$)

ουσιαστικά στατιστικοποιούμε την παγκόσμια σταθερά αερίων

$$P \cdot V = n \cdot R \cdot T \Leftrightarrow R = \frac{P \cdot V}{n \cdot T} = \frac{\frac{N}{\cancel{m^2}} \cdot \cancel{m^3}}{mol \cdot K} =$$

$$R = \frac{\overbrace{N \cdot m}^{J}}{mol \cdot K} = \frac{J}{mol \cdot K}$$

$$\frac{F}{A} \cdot V = n \cdot R \cdot T \Leftrightarrow \frac{F}{\cancel{A}} \cdot \cancel{A} \cdot \ell = nRT \Leftrightarrow F = \frac{n \cdot R \cdot T}{\ell} \Leftrightarrow$$

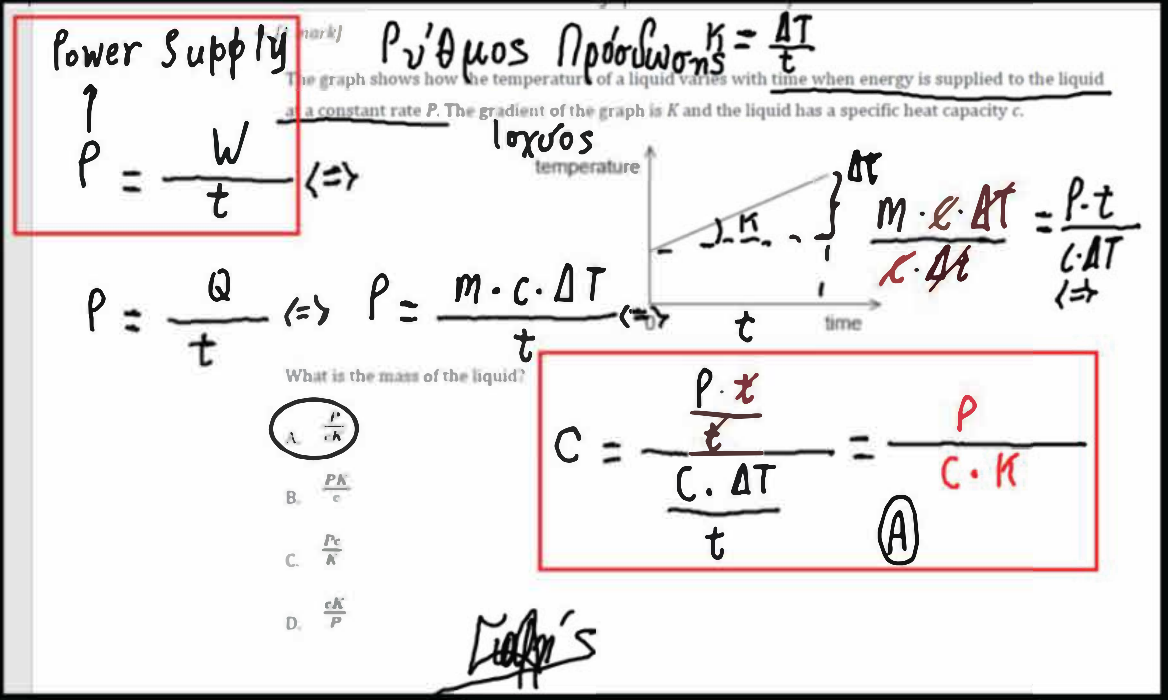
Q = Energy/heat.
m = Mass.
c = Specific heat capacity.
T = Temperature.
L = Specific latent heat.

Sub-topic 3.1 – Thermal concepts		Sub-topic 3.2 – Modelling a gas	
$Q = mc\Delta T$	Energy/heat given/received in changing an object's temperature.	$p = \frac{F}{A}$	Pressure.
$Q = mL$	Energy/heat given/received in changing an object's phase.	$n = \frac{N}{N_A}$	Number of moles of a substance.
		$pV = nRT$	Ideal gas law.
		$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$	Average kinetic energy per molecule of a gas.

$$n = \frac{m}{Mr} = \frac{V}{22.4\,lt} = \frac{N}{N_A}$$

$$F = \frac{N \cdot R \cdot T}{N_A \cdot \ell} \Leftrightarrow \boxed{F = \frac{N \cdot K_B \cdot T}{\ell}}$$

(D)



[1 mark]

Power Supply

↑

$$P = \frac{W}{t} \Leftrightarrow$$

Ρυ'θμος Πρόσδωσης $K = \frac{\Delta T}{t}$

The graph shows how the temperature of a liquid varies with time when energy is supplied to the liquid at a constant rate P. The gradient of the graph is K and the liquid has a specific heat capacity c.

Ισχύος

$$P = \frac{Q}{t} \Leftrightarrow P = \frac{m\cdot c\cdot \Delta T}{t} \Leftrightarrow$$

$$\frac{m\cdot \cancel{c}\cdot \cancel{\Delta T}}{\cancel{c}\cdot \cancel{\Delta t}} = \frac{P\cdot t}{c\cdot \Delta T} \Leftrightarrow$$

What is the mass of the liquid?

[✓ A. $\frac{P}{cK}$]

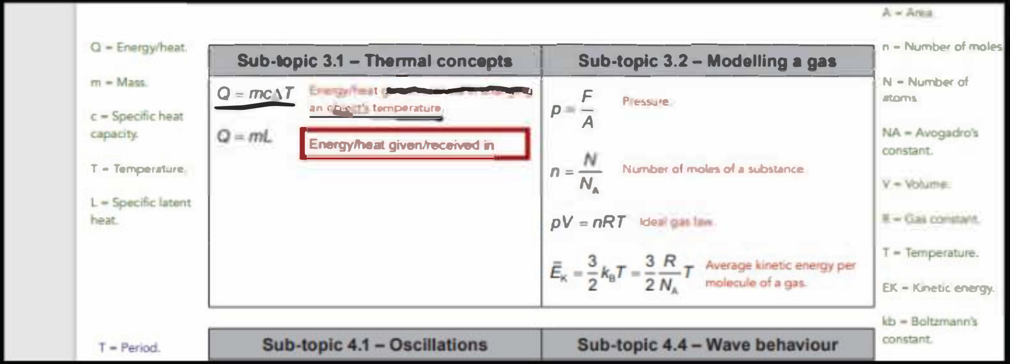
B. $\frac{PK}{c}$

C. $\frac{Pc}{K}$

D. $\frac{cK}{P}$

$$C = \frac{\frac{P\cdot\cancel{t}}{\cancel{t}}}{\frac{C.\Delta T}{t}} = \frac{P}{C\cdot K}$$

Ⓐ



Q – Energy/heat.

m – Mass.

c – Specific heat capacity.

T – Temperature.

L – Specific latent heat.

T – Period.

Sub-topic 3.1 – Thermal concepts		Sub-topic 3.2 – Modelling a gas	
$Q = mc\Delta T$	Energy/heat [redacted] an object's temperature	$p = \frac{F}{A}$	Pressure
$Q = mL$	Energy/heat given/received in	$n = \frac{N}{N_A}$	Number of moles of a substance
		$pV = nRT$	Ideal gas law
		$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$	Average kinetic energy per molecule of a gas.

Sub-topic 4.1 – Oscillations	Sub-topic 4.4 – Wave behaviour

A – Area

n – Number of moles

N – Number of atoms

NA – Avogadro's constant.

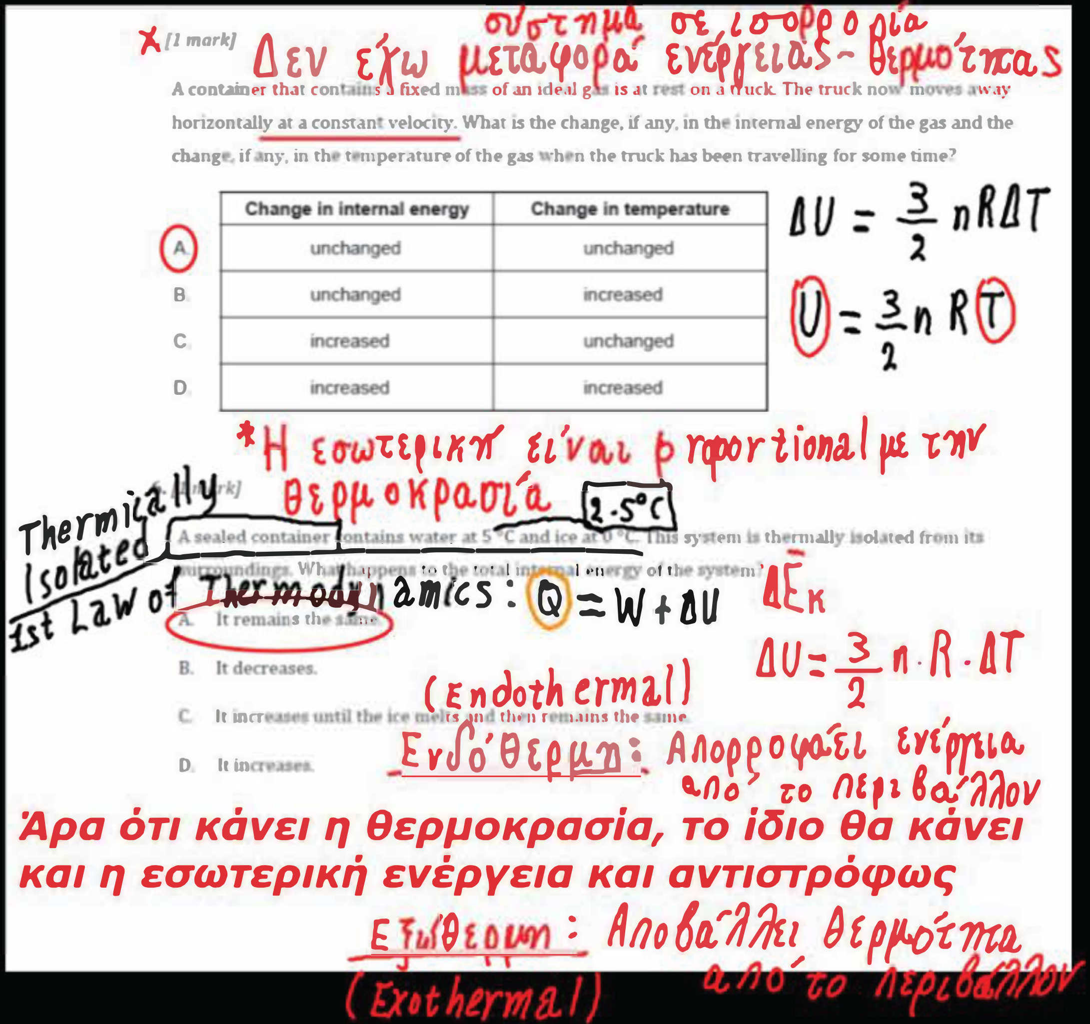
V – Volume.

R – Gas constant.

T – Temperature.

EK – Kinetic energy.

kb – Boltzmann's constant.



✗ [1 mark]

σύστημα σε ισορροπία

Δεν έχω μεταφορά ενέργειας - θερμότητας

A container that contains a fixed mass of an ideal gas is at rest on a truck. The truck now moves away horizontally at a constant velocity. What is the change, if any, in the internal energy of the gas and the change, if any, in the temperature of the gas when the truck has been travelling for some time?

	Change in internal energy	Change in temperature
[✓ A]	unchanged	unchanged
B	unchanged	increased
C	increased	unchanged
D	increased	increased

$$\Delta U = \frac{3}{2} nR\Delta T$$

$$U = \frac{3}{2} nRT$$

*Η εσωτερική είναι proportional με την θερμοκρασία

2.5°C

[1 mark]

Thermically Isolated

A sealed container contains water at 5 °C and ice at 0 °C. This system is thermally isolated from its surroundings. What happens to the total internal energy of the system?

1st Law of ~~Thermody~~namics: $Q = W + \Delta U$

$\Delta \bar{E}_K$

$$\Delta U = \frac{3}{2} n \cdot R \cdot \Delta T$$

[✓ A. It remains the same.]

B. It decreases.

C. It increases until the ice melts and then remains the same.

D. It increases.

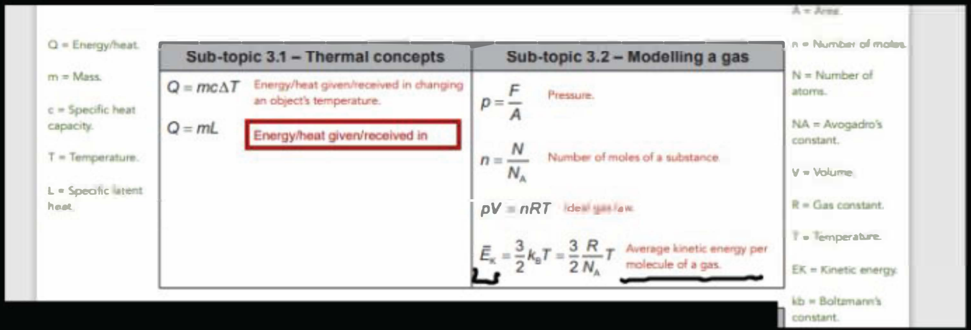
(Endothermal)

Ενδόθερμη: Απορροφάει ενέργεια από το περιβάλλον

Άρα ότι κάνει η θερμοκρασία, το ίδιο θα κάνει και η εσωτερική ενέργεια και αντιστρόφως

Εξώθερμη: Αποβάλλει θερμότητα από το περιβάλλον

(Exothermal)



Q = Energy/heat.

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Sub-topic 3.1 – Thermal concepts		Sub-topic 3.2 – Modelling a gas	
$Q = mc\Delta T$	Energy/heat given/received in changing an object's temperature.	$p = \frac{F}{A}$	Pressure.
$Q = mL$	Energy/heat given/received in	$n = \frac{N}{N_A}$	Number of moles of a substance.
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		$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$	Average kinetic energy per molecule of a gas.

A = Area.

n = Number of moles.

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NA = Avogadro's constant.

V = Volume.

R = Gas constant.

T = Temperature.

EK = Kinetic energy.

kb = Boltzmann's constant.

7. *[1 mark]*

Phase 1 | Phase 2.

Q and R are two rigid containers of volume $3V$ and V respectively containing molecules of the same ideal gas initially at the same temperature. The gas pressures in Q and R are p and $3p$ respectively. The containers are connected through a valve of negligible volume that is initially closed.

$n_{Q\,ini}$ = moles of Q initially | $n_{R\,in.}$ = moles of R initial.

p_f = final pressure

$T_{ini} = T_{Fin} = T$

The valve is opened in such a way that the temperature of the gases does not change. What is the change of pressure in Q?

(temperature)

A. $+p$

[✓ B. $\frac{+p}{2}$]

C. $\frac{-p}{2}$

D. $-p$

$$n_{Q\,ini} + n_{R\,ini} = n_{Q+R\,fin}$$

$$RT\frac{p\cdot 3V}{\cancel{RT}} + RT\frac{3p\cdot V}{\cancel{RT}} = RT\frac{p_f\,4V}{\cancel{RT}} \Leftrightarrow 6p\cancel{V} = 4p_f\cancel{V}$$

$p_f = \frac{3}{2}p$, therefore, $\Delta P_Q = p_f - P_{ini} = \frac{3}{2}p - p = \frac{p}{2}$

The moles are equal before and after the opening of the valve.

8. *[1 mark]*

✓ 8. *[1 mark]*

$$\Delta P = \frac{W}{\Delta t} \quad \text{or} \quad \Delta P = \frac{Q}{\Delta t} .$$

A 1.0 kW heater supplies energy to a liquid of mass 0.50 kg. The temperature of the liquid changes by 80 K in a time of 200 s. The specific heat capacity of the liquid is 4.0 kJ kg^{-1} K^{-1}. What is the average power lost by the liquid?

$$\underline{\text{Power Loss:}} \quad \frac{\text{Energy - Heat}}{\text{Time}}$$

A. 0

B. 200 W

C. 800 W

D. 1600 W

G: given

$$P_G = \frac{m \cdot c \cdot \Delta T}{\Delta t} = \frac{0.5 \cdot 4 \cdot 8\cancel{0}}{20\cancel{0}} = \frac{2 \cdot 8}{20} = 0.8 \text{ kW} = 800W$$

$$P_L = P_{ini} - P_G \Rightarrow P_L = 1000 - 800 \Rightarrow \boxed{P_L = 200W}$$

✓ 9. *[1 mark]*

The fraction of the internal energy that is due to molecular vibration varies in the different states of matter. What gives the order from highest fraction to lowest fraction of internal energy due to molecular vibration?

A. liquid > gas > solid

B. solid > liquid > gas

C. solid > gas > liquid

[✓ D. gas > liquid > solid]

The highest movement of molecules we face it when we have a gas, then a liquid and last a solid.

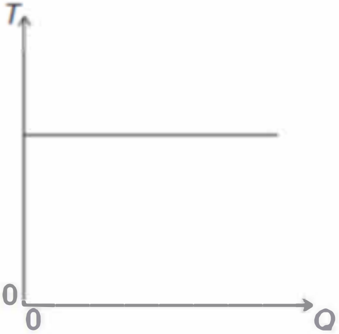
Temperature is at an already low level and all the energy removed from the system is used for the chage of phase

10. *[1 mark]*

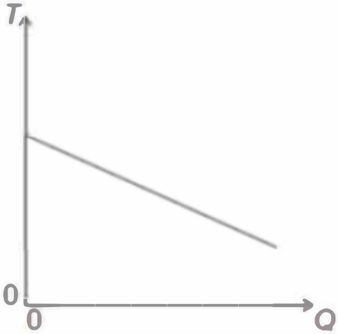
A liquid is initially at its freezing point. Energy is removed at a uniform rate from the liquid until it freezes completely.

Which graph shows how the temperature *T* of the liquid varies with the energy *Q* removed from the liquid?

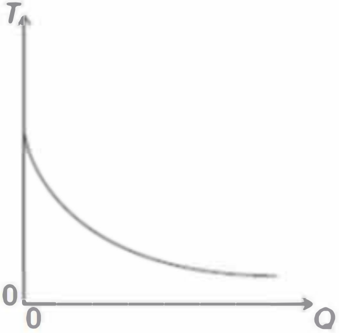
[✓ A.]



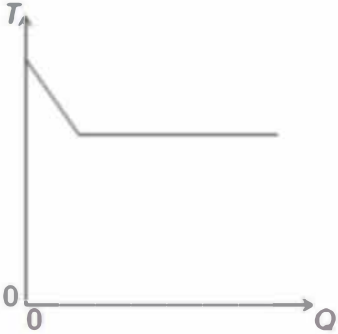
B.



C.

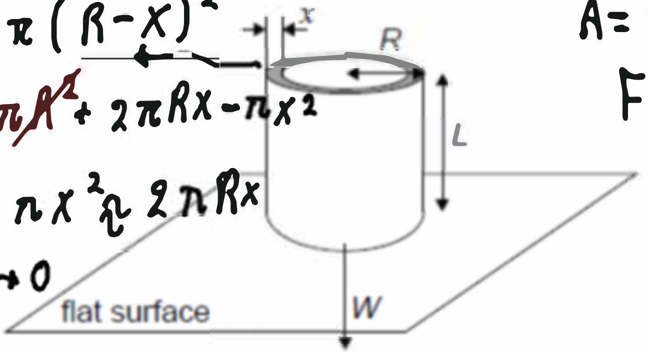


D.



11. *[1 mark]*

A thin-walled cylinder of weight W, open at both ends, rests on a flat surface. The cylinder has a height L, an average radius R and a thickness x where R is much greater than x.



$$A = \pi R^2 - \pi (R-x)^2$$

$$A = \cancel{\pi R^2} - \cancel{\pi R^2} + 2\pi R x - \pi x^2$$

$$A = 2\pi R x - \pi x^2 \approx 2\pi R x$$

because $x \to 0$

A= area

$F = W$

What is the pressure exerted by the cylinder walls on the flat surface?

A. $\frac{W}{2\pi R x}$

B. $\frac{W}{\pi R^2 x}$

C. $\frac{W}{\pi R^2}$

D. $\frac{W}{\pi R^2 L}$

$$P = \frac{F}{A} = \frac{W}{A} = \frac{W}{2\pi R x}$$

B

12. *[1 mark]*

The graph shows the variation with time *t* of the temperature *T* of two sample

the same mass and are initially in the solid phase. Thermal energy is being pro

same constant rat

$m_x = m_y$

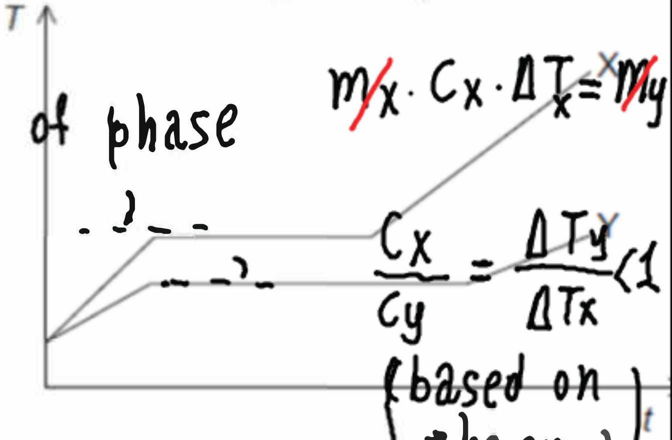
$P_x = P_y \Rightarrow \frac{Q_x}{\cancel{t}} = \frac{Q_y}{\cancel{t}} \Rightarrow$

change of phase

$\cancel{m_x} \cdot c_x \cdot \Delta T_x = \cancel{m_y} \cdot c_y \cdot \Delta T_y$

$\frac{c_x}{c_y} = \frac{\Delta T_y}{\Delta T_x} < 1$

(based on the graph)



What is the correct comparison of the specific latent heats L_X and L_Y and speci

liquid phase c_X and c_Y of X and Y?

$\frac{c_x}{c_y} < 1 \Rightarrow c_x < c_y$

A.	$L_X > L_Y$	$c_X > c_Y$
B.	$L_X > L_Y$	$c_X < c_Y$
C.	$L_X < L_Y$	$c_X > c_Y$
[✓ D.]	$L_X < L_Y$	$c_X < c_Y$

13. *[1 mark]*

A mass m of ice at a temperature of –5 °C is changed into water at a temperature of 50 °C.

Specific heat capacity of ice = c_i

Specific heat capacity of water = c_w

Specific latent heat of fusion of ice = L

$$\Big\}\ m \cdot C_1 \cdot \Delta T_1 + mL + m \cdot C_w \cdot \Delta T_2$$

Which expression gives the energy needed for this change to occur?

$$\left.\begin{array}{l} T_{ini} = -5 \\ T_{fin_1} = 0 \end{array}\right\} \quad \Delta T_1 = 0 - (-5) = 5$$

A. $55\, m\, c_w + m\, L$

B. $55\, m\, c_i + 5\, m\, L$

[✓ C. $5\, m\, c_i + 50\, m\, c_w + m\, L$]

D. $5\, m\, c_i + 50\, m\, c_w + 5\, m\, L$

$$5m\, C_1 + mL + 50 m\, C_w$$

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Sub-topic 3.1 – Thermal concepts		**Sub-topic 3.2 – Modelling a gas**	
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14. *[1 mark]*

A sealed container contains a mixture of oxygen and nitrogen gas.

The ratio $\frac{\text{mass of an oxygen molecule}}{\text{mass of a nitrogen molecule}}$ is $\frac{8}{7}$.

The ratio $\frac{\text{average kinetic energy of oxygen molecules}}{\text{average kinetic energy of nitrogen molecules}}$ is

A. 1.

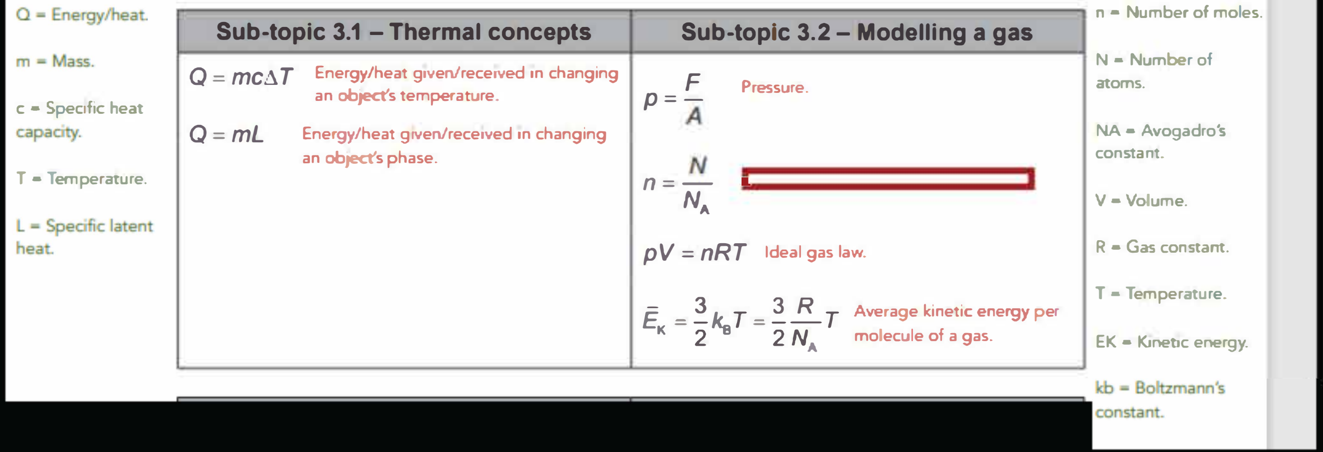
B. $\frac{7}{8}$.

C. $\frac{8}{7}$.

D. dependent on the concentration of each gas.

$$\frac{\bar{E}_{K_O} = \cancel{\frac{3}{2}} \cdot \cancel{\frac{R}{N_A}} \cdot \cancel{T}}{\bar{E}_{K_{Ni}} = \cancel{\frac{3}{2}} \cdot \cancel{\frac{R}{N_A}} \cdot \cancel{T}}$$

$$\frac{\bar{E}_{K_O}}{\bar{E}_{K_{Ni}}} = 1$$



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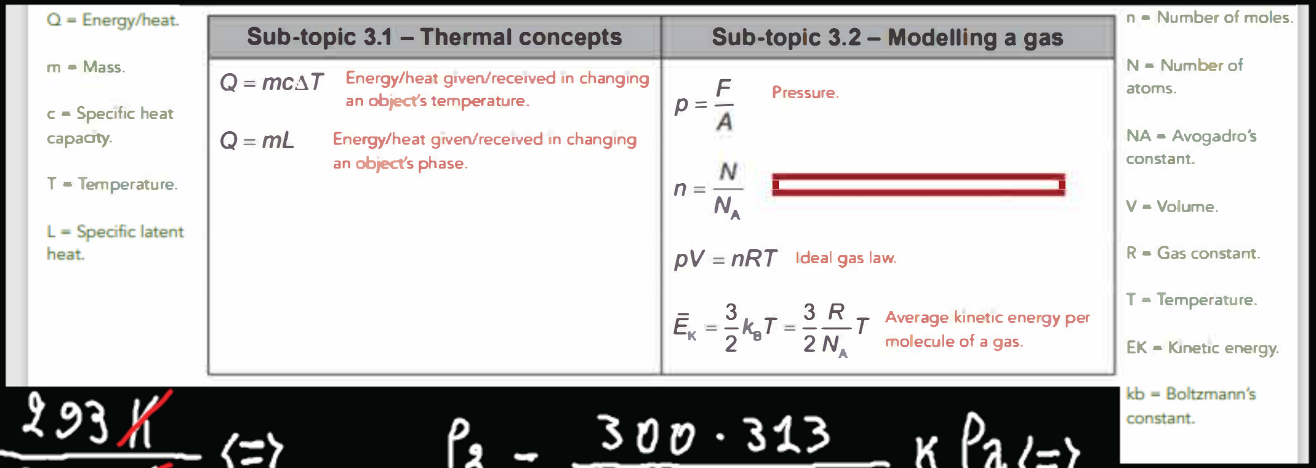

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15. *[1 mark]*

An ideal gas has a volume of 15 ml, a temperature of 20 °C and a pressure of 100 kPa. The volume of the gas is reduced to 5 ml and the temperature is raised to 40 °C. What is ~~the~~ approximately the new pressure of the gas?

A. 600 kPa

[✓ B. 320 kPa]

C. 200 kPa

D. 35 kPa

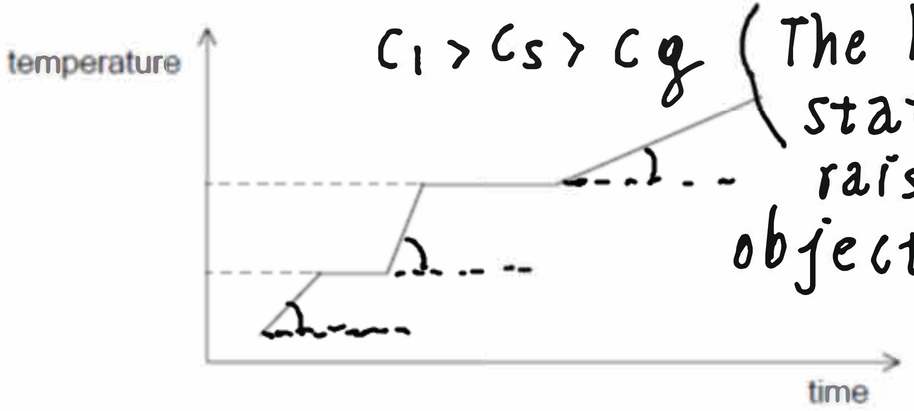
$$\left.\begin{array}{l} T_1 = 20°C = 293\,K \\ T_2 = 40°C = 313\,K \end{array}\right\} \quad \left.\begin{array}{l} V_1 = 15\,mL \\ V_2 = 5\,mL \end{array}\right\}$$

$$\frac{P_1 \cdot V_1}{P_2 \cdot V_2} = \frac{\cancel{n} \cdot \cancel{R} \cdot T_1}{\cancel{n} \cdot \cancel{R} \cdot T_2} \Leftrightarrow \frac{100\,kPa \cdot \overset{3}{\cancel{15}}\,\cancel{m}L}{P_2 \cdot \cancel{5}\,\cancel{m}L} = \frac{293\,\cancel{K}}{313\,\cancel{K}} \Leftrightarrow P_2 = \frac{300 \cdot 313}{293}\,kPa \Leftrightarrow$$

$$\boxed{P_2 \simeq 320\,kPa}$$

16. *[1 mark]*

Energy is supplied at a constant rate to a fixed mass of a material. The material begins as a solid. The graph shows the variation of the temperature of the material with time.



Based on the graph

$C_l > C_s > C_g$ (The hardest state to raise the objects temperature is the liquid, then the solid and then the gas)

The specific heat capacities of the solid, liquid and gaseous forms of the material are c_s c_l and c_g respectively. What can be deduced about the values of c_s c_l and c_g?

A. $c_s > c_g > c_l$

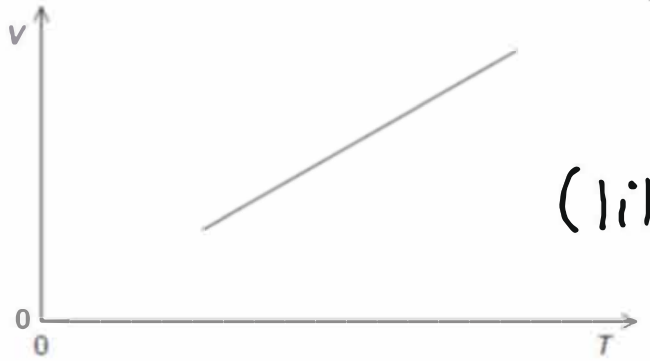
[✓ B. $c_l > c_s > c_g$]

C. $c_l > c_g > c_s$

D. $c_g > c_s > c_l$

✓ **17.** *[1 mark]*

An ideal gas of N molecules is maintained at a constant pressure p. The graph shows how the volume V of the gas varies with absolute temperature T.



$$P\cdot V = n\cdot R\cdot T \Leftrightarrow$$

$$V = \frac{n\cdot R}{P}\cdot T$$

(like $y = a\cdot x$)

$$\boxed{a = \frac{n\cdot R}{P}} \Rightarrow$$

$$\boxed{a = \frac{N\cdot R}{N_A\cdot P} = \frac{N\cdot K_B}{P}}$$

What is the gradient of the graph?

A. $\frac{N}{p}$

B. $\frac{NR}{p}$

[✓ C. $\frac{Nk_B}{p}$]

D. $\frac{N}{Rp}$

✓ **18.** *[1 mark]*

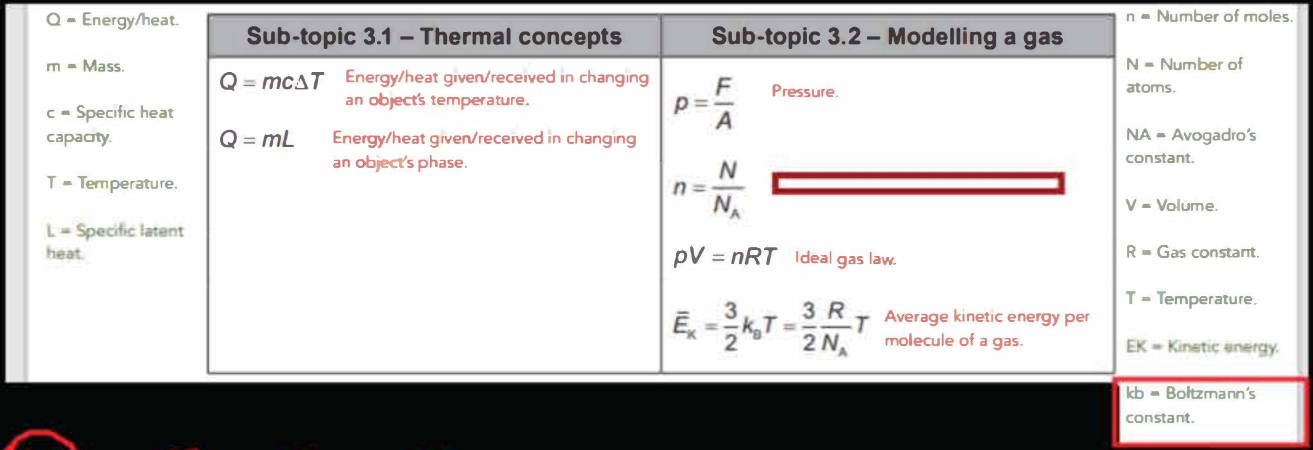
The pressure of a fixed mass of an ideal gas in a container is decreased at constant temperature. For the molecules of the gas there will be a decrease in

A. the mean square speed.

[✓ B. the number striking the container walls every second.]

C. the force between them.

D. their diameter.



Sub-topic 3.1 – Thermal concepts		Sub-topic 3.2 – Modelling a gas	
$Q = mc\Delta T$	Energy/heat given/received in changing an object's temperature.	$p = \frac{F}{A}$	Pressure.
$Q = mL$	Energy/heat given/received in changing an object's phase.	$n = \frac{N}{N_A}$	
		$pV = nRT$	Ideal gas law.
		$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$	Average kinetic energy per molecule of a gas.

Q = Energy/heat.
m = Mass.
c = Specific heat capacity.
T = Temperature.
L = Specific latent heat.

n = Number of moles.
N = Number of atoms.
NA = Avogadro's constant.
V = Volume.
R = Gas constant.
T = Temperature.
EK = Kinetic energy.
kb = Boltzmann's constant.

⑱ $T_1 = T_2 = T$

$$\frac{P_1\cdot V_1 = \cancel{n}\cdot\cancel{R}\cdot\cancel{T_1}\ 1}{P_2\cdot V_2 = \cancel{n}\cdot\cancel{R}\cdot\cancel{T_2}\ 1} \Leftrightarrow \boxed{P_1\cdot V_1 = P_2\cdot V_2} \Leftrightarrow$$

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \Rightarrow \frac{\cancel{P_2}^{\,1}}{\cancel{P_2}\,1} < \frac{P_1}{P_2} \Leftrightarrow$$

$$\frac{P_1}{P_2} > 1 \Rightarrow \frac{V_2}{V_1} > 1 \Rightarrow V_2 > V_1 \Rightarrow$$

In order for the Volume to be increased, the particles have to strike the container walls at an increased rate.

20. *[1 mark]*

Under what conditions of density and pressure is a real gas best described by the equation of state for an ideal gas?

[✓ A. Low density and low pressure]

B. Low density and high pressure

C. High density and low pressure

D. High density and high pressure

In order to have an ideal gas, a very standard set of measurements is the following: V=22.4 lt | b = 1atm

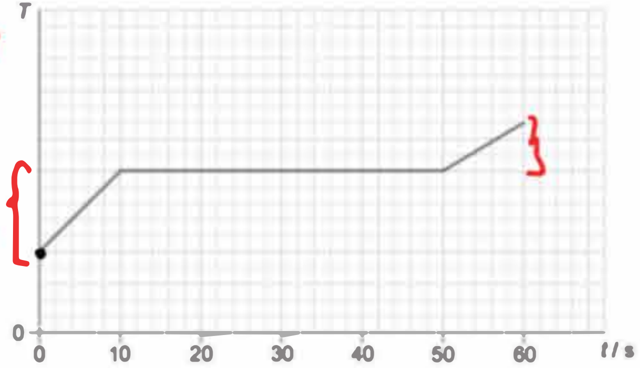
T = 300K

21. *[1 mark]*

A container with 0.60kg of a liquid substance is placed on a heater at time *t*=0. The specific latent heat of vaporization of the substance is 200kJkg⁻¹. The graph shows the variation of the temperature *T* of the substance with time *t*.

$$P = \frac{Q}{t} \Leftrightarrow$$

$$P = \frac{m \cdot L_v}{t}$$



$L_v = 2 \cdot 10^5 J/Kg$

$m = 0.6$

$$P = \frac{\overset{3}{\cancel{6}} \cdot 10^{-1} \cancel{Kg} \cdot \overset{1}{\cancel{2}} \cdot 10^5 \cancel{J/Kg}}{\cancel{4} \cdot 10 \ S}$$

What is the power of the heater?

A. 1200 W

[✓ B. 3000 W]

C. 4800 W

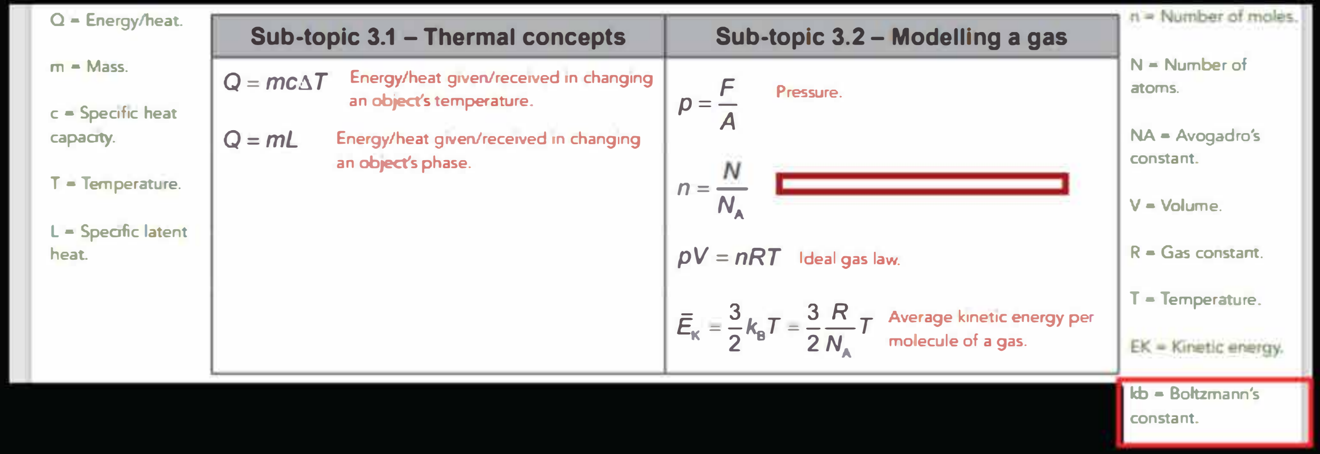
D. 13 300 W

$$\frac{m \cdot L_v}{40}$$

$$P = \frac{3 \cdot \cancel{10^1} \cdot 10^5}{\cancel{10^2}}$$

$$\boxed{P = 3{,}000 W}$$

W



Q = Energy/heat.

m = Mass.

c = Specific heat capacity.

T = Temperature.

L = Specific latent heat.

Sub-topic 3.1 – Thermal concepts	Sub-topic 3.2 – Modelling a gas
$Q = mc\Delta T$ Energy/heat given/received in changing an object's temperature.	$p = \frac{F}{A}$ Pressure.
$Q = mL$ Energy/heat given/received in changing an object's phase.	$n = \frac{N}{N_A}$
	$pV = nRT$ Ideal gas law.
	$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$ Average kinetic energy per molecule of a gas.

n = Number of moles.

N = Number of atoms.

NA = Avogadro's constant.

V = Volume.

R = Gas constant.

T = Temperature.

EK = Kinetic energy.

kb = Boltzmann's constant.

We do not take into account time intervals from 0-10 seconds and 50-60 seconds as well, we only consider the transition phase from 10-50 seconds.

From 50-60 seconds the heater doesn't need to work since, the liquid has completely been transformed into gas (vaporization), thus the heater isn't required to operate.