MOLAR SPECIFIC HEAT AT CONSTANT VOLUME

THE INITIAL STATE OF THE GAS IS HEATED TO FINAL STATE

HEAT = Q

$$Q = n C_V \Delta T$$

CHANGE IN INTERNAL ENERGY

$$\Delta E_{int} = n C_V \Delta T - W$$

W = WORK DONE

IF W = 0

$$\Delta E_{int} = n C_V \Delta t$$

$$C_V = \frac{\Delta E_{int}}{n \Delta t}$$

CHANGE I

$\Delta S = S_f$

HEAT LOSS

ΔS gas

HEAT GAIN

ΔS g

FORCE

TO FINAL STATE

CHANGE IN ENTROPY

$$\Delta S = S_f - S_i = \int_i^f \frac{dQ}{T}$$

HEAT LOSS

$$\Delta S_{gas} = -\frac{|Q|}{T}$$

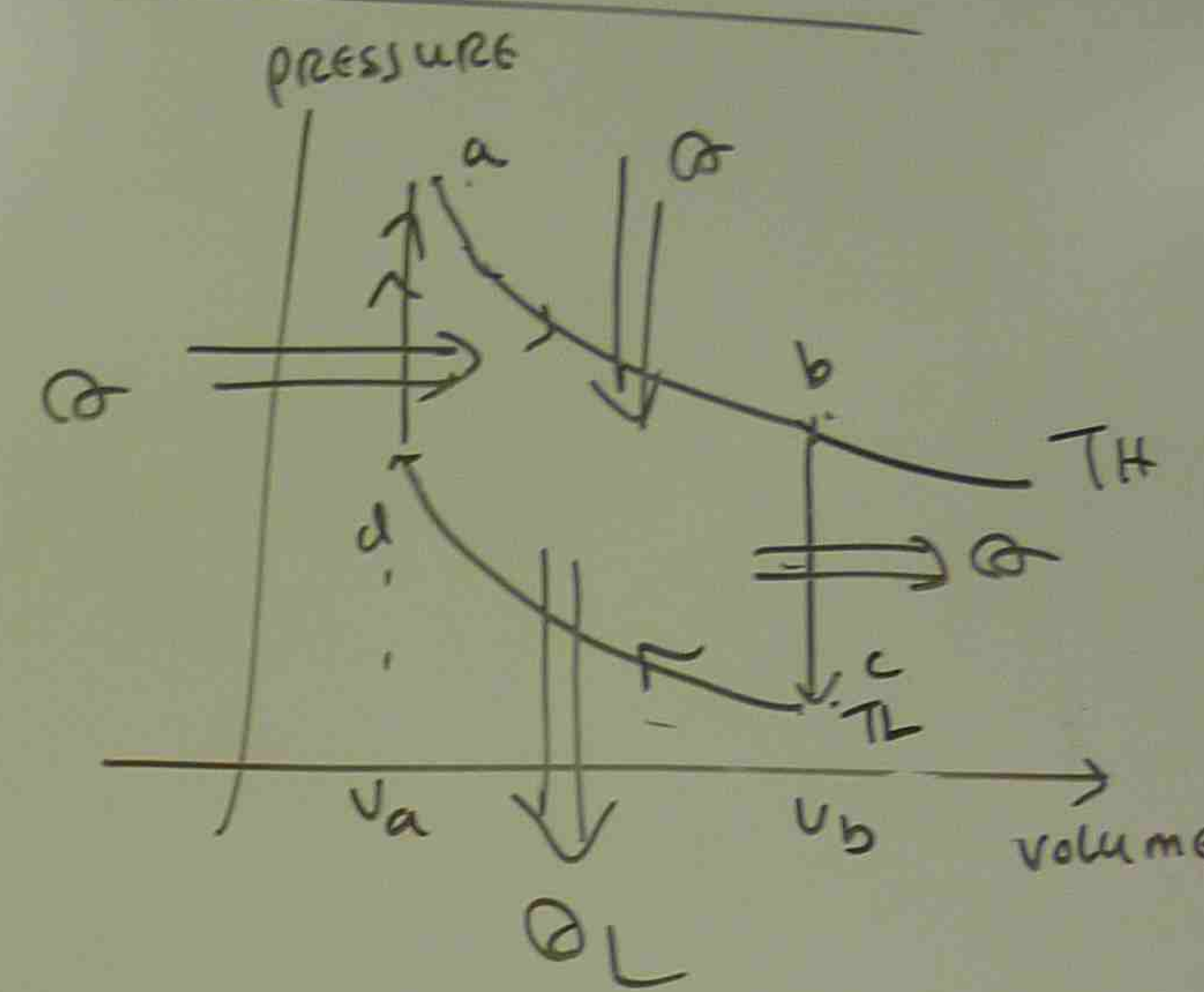
HEAT GAIN

$$\Delta S_{gas} = +\frac{|Q|}{T}$$

FORCE DUE TO ENTROPY

$$dE = dQ - dW$$

STIRLING ENGINE



CARNOT CYCLE

COMPRESS THE GAS $c \to d$

VOLUME $V_b \to V_a$

HEAT Q_L DISSIPATES

HEAT THE GAS AT $d - a$

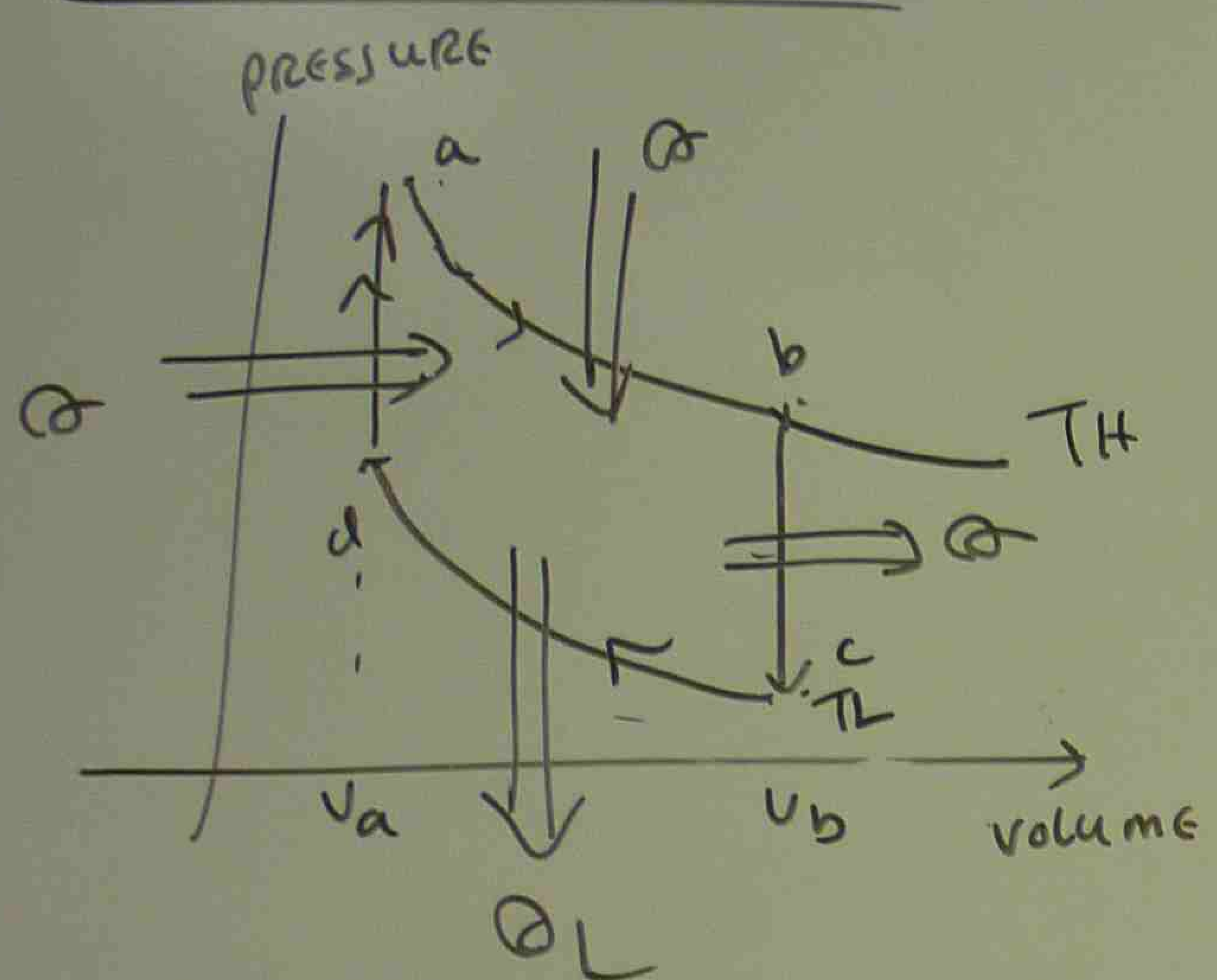
TEMPERATURE RISES FROM T_L TO T_H

PRESSURE INCREASED

HEAT ABSORBED.

COOLING

STIRLING ENGINE



CARNOT CYCLE

COMPRESS THE GAS c → d

VOLUME $V_b \to V_a$

HEAT Q_L DISSIPATES

HEAT THE GAS AT d – a

TEMPERATURE RISES FROM T_L TO T_H

PRESSURE INCREASED

HEAT ABSORBED.

EXPANSION

a → b

VOLUME $V_a \to V_b$

COOLING b → c

HEAT DISSIPATED

TEMPERATURE DECREASES

FROM T_H TO T_L

Pb THREE CARNOT ENGINES OPERATE BETWEEN RESERVOIR TEMPERATURES OF (a) 400K AND 500K (b) 600 AND 800K (c) 400 AND 600K. RANK THE ENGINES ACCORDING TO THEIR THERMAL EFFICIENCIES. GREATEST FIRST.

$$\text{Efficiency} = 1 - \frac{T_L}{T_H}$$

(a) $1 - \frac{400}{500} = 1 - 0.8 = 0.2 - 20\%$

(b) $1 - \frac{600}{800} = 1 - 0.75 = 0.25 \to 25\%$

(c) $1 - \frac{400}{600} = 1 - 0.66 = 0.34 \to 34\%$

c, b, a

operate between
of (a) 400K and 500K
(b) 400 and 600K. Rank
to their thermal
first.

c, b, a

20%

→25%

→34%

P7 Imagine a Carnot engine that operates between the temperatures $T_H = 850K$ and $T_L = 300K$. The engine performs 1200 J of work each cycle, which takes 0.25 sec

(a) What is the efficiency of this engine?

(b) What is the average power "P" of this engine?

(c) How much energy $|Q_H|$ is extracted as heat from the high temperature reservoir every cycle?

(d) How much energy $|Q_L|$ is delivered as heat to the low temperature reservoir every cycle?

(e) By how much does the entropy of working substance change as a result of the energy transferred to it from the high temperature reservoir? From it to the low temperature reservoir?

(a) $e = 1 - \frac{T_L}{T_H} = 1 - \frac{300K}{850K}$

(b) $P = \frac{W}{t} = \frac{1200}{0.25} = 480$

(c) $|Q_H| = \frac{W}{e} = \frac{12}{0}$

(d) $|Q_L| = |Q_H| - W$

$= 1855 - 120$

$= 655 J$

(e) $\Delta S_H = \frac{Q_H}{T_H} =$

$\Delta S_L = \frac{Q_L}{T_L} =$

negativ

tra

$\Delta S = \Delta S_H +$

INE THAT OPERATES BETWEEN
850K AND $T_L = 300K$.
00 J of WORK EACH CYCLE.

ENCY OF THIS ENGINE?
AGE POWER "p" of THIS

$|Q_H|$ IS EXTRACTED
E HIGH TEMPERATURE
CYCLE?
$|Q_L|$ IS DELIVERED
LOW TEMPERATURE
CYCLE?
DOES THE ENTROPY
STANCE CHANGE AS A
ENERGY TRANSFERRED TO
HIGH TEMPERATURE
FROM IT TO THE LOW
E RESERVOIR?

(a) $e = 1 - \frac{T_L}{T_H} = 1 - \frac{300K}{850K} = 0.647 \Rightarrow 65\%$

(b) $P = \frac{W}{t} = \frac{1200}{0.25} = 4800W = 4.8kW$

(c) $|Q_H| = \frac{W}{e} = \frac{1200J}{0.647} = 1855 J$

(d) $|Q_L| = |Q_H| - W$

$= 1855 - 1200$

$= 655 J$

(e) $\Delta S_H = \frac{Q_H}{T_H} = \frac{1855}{850} = 2.18 J/K$

$\Delta S_L = \frac{Q_L}{T_L} = \frac{-655}{300} = -2.18 J/K$

NEGATIVE

TRANSFER

$\Delta S = \Delta S_H + \Delta S_L = 2.18 + (-2.18)$

$= 0$

(h) AN INVENTOR C
THAT HAS AN EFFICIE
THE BOILING AND
POSSIBLE?

$e = 1 - \frac{T_L}{T_H} =$

IMPOSSI

$647 \Rightarrow 65\%$

$.8\,kW$

$= 1855\ J$

$= 2.18\ J/K$

$= -2.18\ J/K$

$2.18 + (-2.18)$

$= 0$

P7. AN INVENTOR CLAIMS TO HAVE CONSTRUCTED AN ENGINE THAT HAS AN EFFICIENCY OF 75% WHEN OPERATED BETWEEN THE BOILING AND FREEZING POINTS OF WATER, IS THIS POSSIBLE?

$$e = 1 - \frac{T_L}{T_H} = 1 - \frac{(0+273)\,K}{(100+273)\,K} = 1 - \frac{273}{373}$$

$$= 0.268 \simeq 27\%$$

IMPOSSIBLE

…7 ⇒ 65%

…w

1855 J

2.18 J/K

−2.18 J/K

18+(−2.18)

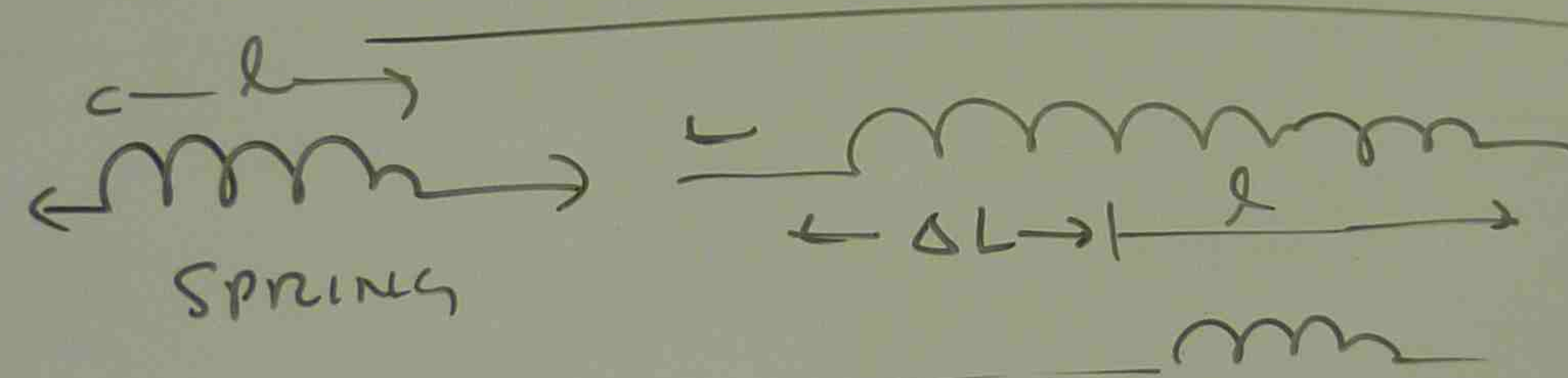
pb AN INVENTOR CLAIMS TO HAVE CONSTRUCTED AN ENGINE THAT HAS AN EFFICIENCY OF 75% WHEN OPERATED BETWEEN THE BOILING AND FREEZING POINTS OF WATER, IS THIS POSSIBLE?

$$e = 1 - \frac{T_L}{T_H} = 1 - \frac{(0+273)\,K}{(100+273)\,K} = 1 - \frac{273}{373}$$

$$= 0.268 \simeq 27\%$$

IMPOSSIBLE

HARMONIC MOTION AND WAVE



ANGULAR VELOCITY $\omega = \sqrt{\frac{k}{m}}$

k = SPRING CONSTANT

m = MASS

FREQUENCY $f = \frac{\omega}{2\pi}$

PERIOD $T = \frac{1}{f}$

pb THE BLOCK WHOSE M…
IS FASTENED TO A SPRING…
k IS 65 N/m. THE B…
DISTANCE X = 11 cm…
POSITION AT X = 0 ON…
SURFACE AND RELEASES…
t = 0.

(a) WHAT ARE ANGUL… FREQUENCY AND TH… MOTION?

(b) WHAT IS THE A…

(c) WHAT IS THE MA… THE OSCILLATING BLOC… BLOCK WHEN IT H…

(d) WHAT IS THE MA…

(e) WHAT IS THE PH… MOTION

(f) WHAT IS THE

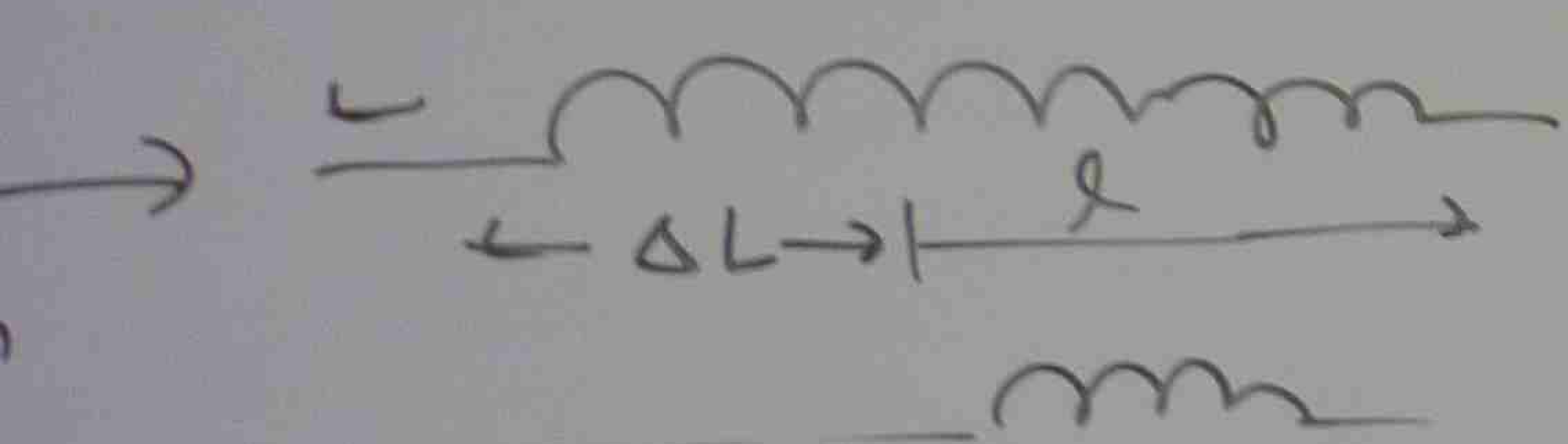
...VENTOR CLAIMS TO HAVE CONSTRUCTED AN ENGINE
... AN EFFICIENCY OF 75% WHEN OPERATED BETWEEN
...G AND FREEZING POINTS OF WATER, IS THIS

$$\frac{T_C}{T_H} = 1 - \frac{(0+273)\,K}{(100+273)\,K} = 1 - \frac{273}{373}$$

$$= 0.268 \simeq 27\%$$

...M POSSIBLE

...HARMONIC MOTION AND WAVE



...ULAR VELOCITY $\omega = \sqrt{\frac{K}{m}}$

K = SPRING CONSTANT

m = MASS

...REQUENCY $f = \frac{\omega}{2\pi}$

PERIOD $T = \frac{1}{f}$

pb THE BLOCK WHOSE MASS "m" IS 680 g IS FASTENED TO A SPRING WHOSE SPRING CONSTANT k IS 65 N/m. THE BLOCK IS PULLED A DISTANCE $X = 11$ cm FROM IT'S EQUILIBRIUM POSITION AT $X = 0$ ON A FRACTION LESS SURFACE AND RELEASED FROM REST AT $t = 0$.

(a) WHAT ARE ANGULAR FREQUENCY, THE FREQUENCY AND THE PERIOD OF RESULTING MOTION?

(b) WHAT IS THE AMPLITUDE OF OSCILLATION?

(c) WHAT IS THE MAXIMUM SPEED V_m OF THE OSCILLATING BLOCK AND WHERE IS THE BLOCK WHEN IT HAS THIS PERIOD?

(d) WHAT IS THE MAGNITUDE OF ACCELERATION?

(e) WHAT IS THE PHASE CONSTANT ϕ FOR THE MOTION

(f) WHAT IS THE DISPLACEMENT FUNCTION?

(a) $\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{65}{0.68}} = 9.78$ RAD/s

$f = \frac{\omega}{2\pi} = \frac{9.78}{2 \times 3.1416} = 1.6$ Hz

$T = \frac{1}{f} = \frac{1}{1.6} = 0.64$ sec $= 640$ ms

(b) $x_m = 11$ cm

(c) $V_m = \omega x_m = 9.78 \times \frac{11}{100} = 1.1$ m/s

(d) $a_m = \omega^2 x_m = (9.78)^2 \times \frac{11}{100}$

$= 11$ m/s^2

(e) AT TIME $t = 0$

$x = x_m$

$\cos\phi = \frac{x}{x_m}$

$\cos\phi = \frac{\cancel{x}}{\cancel{x_m}}$

$\cos\phi = 1$

$\phi = 0°$

(f)

$x(t) = x_m \cos(\omega t + \phi)$

$= (0.11\text{m}) \cos(9.78t + \phi)$

$= 0.11 \cos(9.78t + 0)$

$x(t) = 0.11 \cos 9.78t$

(a)

$\frac{1}{3}$

pb At $t = 0$ THE DISPLACEMENT $x(0)$ OF THE BLOCK IS -8.5 cm THE BLOCK'S VELOCITY $v(0)$ IS -0.92 m/s AND IT'S ACCELERATION $a(0)$ IS 47 m/s^2

(a) WHAT IS THE ANGULAR VELOCITY ω OF THIS SYSTEM?

(b) WHAT ARE THE PHASE CONSTANT ϕ AND AMPLITUDE x_m?

$+\phi)$

$t+\phi)$

$t+\phi)$

t

PLACEMENT

S -8.5 cm

$V(0)$ IS

ACCELERATION

AR VELOCITY

m?

HASE CONSTANT

E X_m?

(a)

$$x(0) = x_m \cos\phi \quad \text{--- } 1$$
$$v(0) = -\omega x_m \sin\phi \quad \text{--- } 2$$
$$a(0) = -\omega^2 x_m \cos\phi \quad \text{--- } 3$$

$$\frac{1}{3} \quad \frac{x(0)}{a(0)} = \frac{x_m \cos\phi}{-\omega^2 x_m \cos\phi}$$

$$\frac{x(0)}{a(0)} = -\frac{1}{\omega^2}$$

$$\omega^2 = -\frac{a(0)}{x(0)}$$

$$\omega = \sqrt{-\frac{a(0)}{x(0)}}$$

$$= \sqrt{-\frac{47}{(-8.5)}}$$

$$= 23.5 \text{ RAD/s}$$

(b)

$$\frac{2}{1} \Rightarrow \frac{v(0)}{x(0)} = \frac{-\omega x_m \sin\phi}{x_m \cos\phi}$$

$$\frac{v(0)}{x(0)} = -\omega \tan\phi$$

$$\tan\phi = -\frac{v(0)}{\omega x(0)} = -\frac{(-0.92)}{23.5 \times (-8.5)}$$

$$= -0.461$$

$$\phi = -25^\circ \text{ (OR) } 155^\circ$$

$$x_m = \frac{x(0)}{\cos\phi} \Rightarrow$$

$$\phi = -25 \longrightarrow x_m = \frac{-0.085}{\cos(-25)} = -0.094\text{m} = -9.4\text{cm}$$

$$\phi = 155 \longrightarrow x_m = \frac{0.085}{\cos 155} = 0.094\text{m} = 9.4\text{cm}$$

ENERG

$U(t)=$

DAM

m

$x(t)$

$\omega' =$

$-0.094\,m$
$= -9.4\,cm$

$0.094\,m$

$= 9.4\,cm$

ENERGY IN SIMPLE HARMONIC MOTION

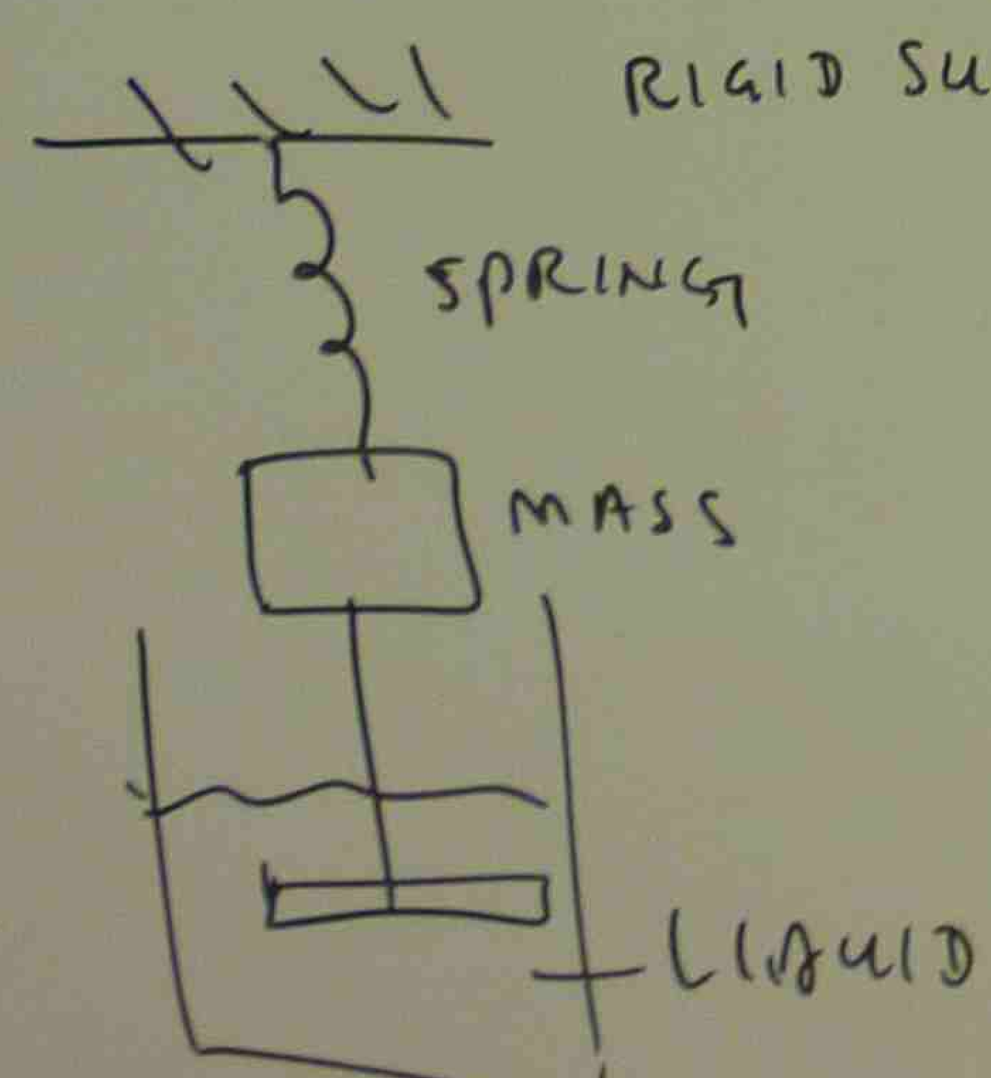
$$U(t) = \frac{1}{2} k x^2 = \frac{1}{2} k x_m^2 \cos^2(\omega t + \phi)$$

DAMPED SIMPLE HARMONIC MOTION

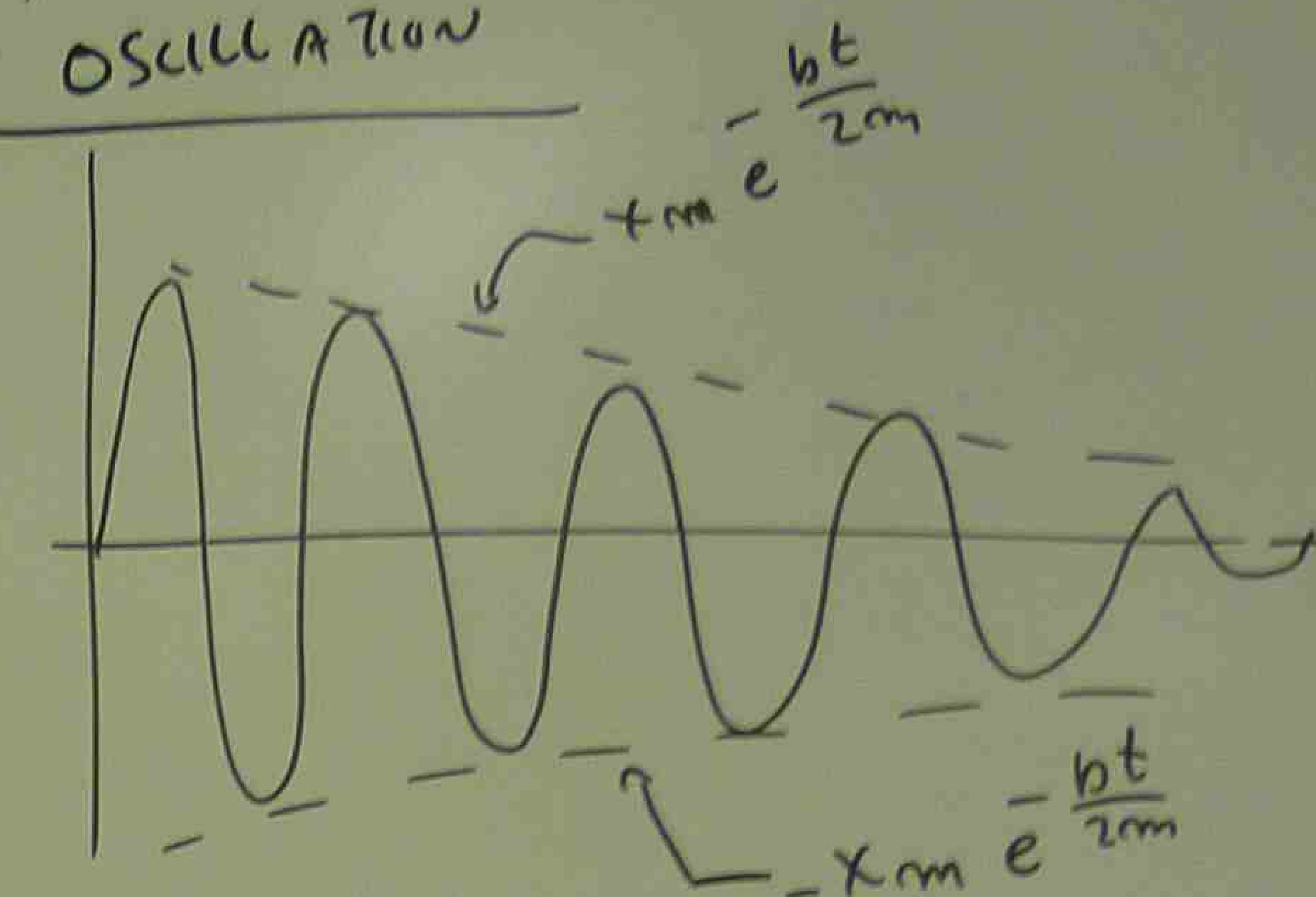
$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

$$x(t) = x_m e^{-\frac{bt}{2m}} \cos(\omega' t + \phi)$$

$$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$



OSCILLATION



$$E(t) = \frac{1}{2} k x_m^2 e^{-\frac{bt}{m}}$$

PB FOR THE DAMPED OSCILLATOR
$m = 250\,g$, $k = 85\,N/m$ $b = 70\,g/s$

(a) WHAT IS THE PERIOD OF THE MOTION?

(b) HOW LONG DOES IT TAKE FOR THE AMPLITUDE OF THE DAMPED OSCILLATIONS TO DROP TO HALF IT'S INITIAL VALUE?

(c) HOW LONG DOES IT TAKE FOR THE MECHANICAL ENERGY TO DROP TO ONE HALF IT'S INITIAL VALUE?

(a) $T =$

(b)

(c

(a) $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.25}{85}} = 0.34$ sec

(b)

$$x(t) = x_m\, e^{-\frac{bt}{2m}}$$

$$\frac{1}{2}x_m = x_m\, e^{-\frac{bt}{2m}}$$

$$0.5 = e^{-\frac{bt}{2m}}$$

$$\ln 0.5 = -\frac{bt}{2m}$$

$$t = \frac{2m \ln 0.5}{-b}$$

$$= \frac{-2 \times 0.25 \ln 0.5}{0.070}$$

$$= 5 \text{ sec}$$

(c)

$$\frac{1}{2}k x_m^2\, e^{-\frac{bt}{m}} = \frac{1}{2}\left(\frac{1}{2}k x_m^2\right)$$

$$e^{-\frac{bt}{m}} = 0.5$$

$$-\frac{bt}{m} = \ln 0.5$$

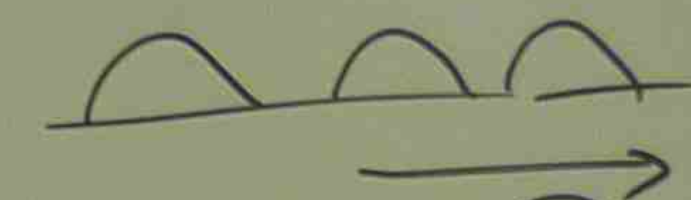
$$t = -\frac{\ln 0.5 \times m}{b} = \frac{-\ln 0.5 \times 0.25}{0.070} = 2.5 \text{ sec}$$

TYPES OF WAVES

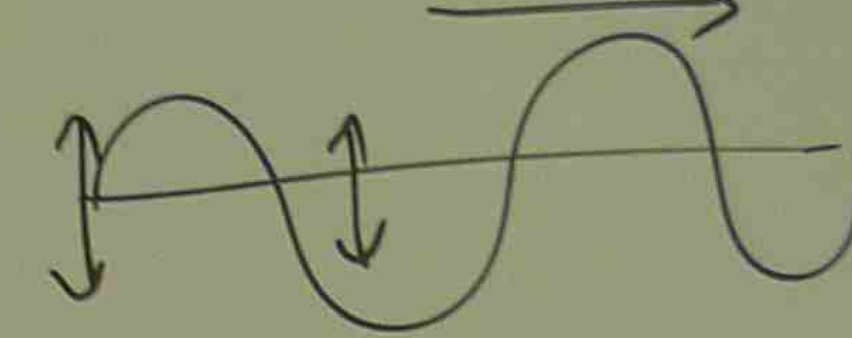
MECHANICAL WAVE

ELECTROMAGNETIC WAVE

MATTER WAVE



PULSE

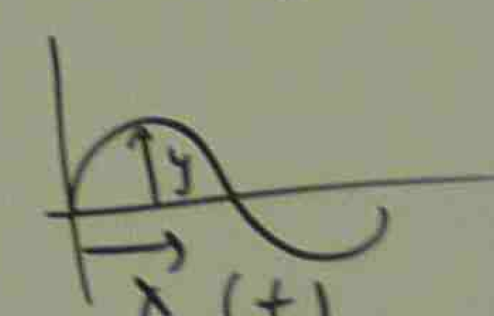


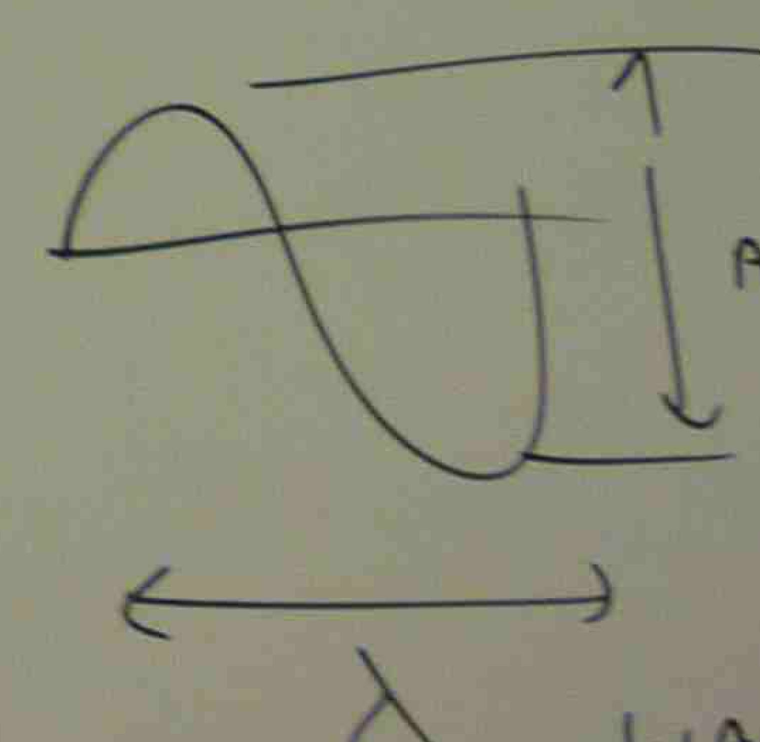
SINUSOIDAL WAVE

LONGITUDINAL WAVE

TRANSVERSE WAVE

$$y(x,t) = y_m \sin(kx - \omega t)$$



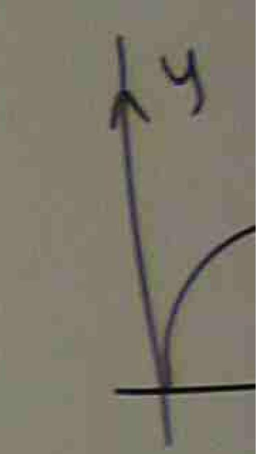


K = A

ANGUL

FRE

λ =



G

THE S

Kx

V =

LINEA

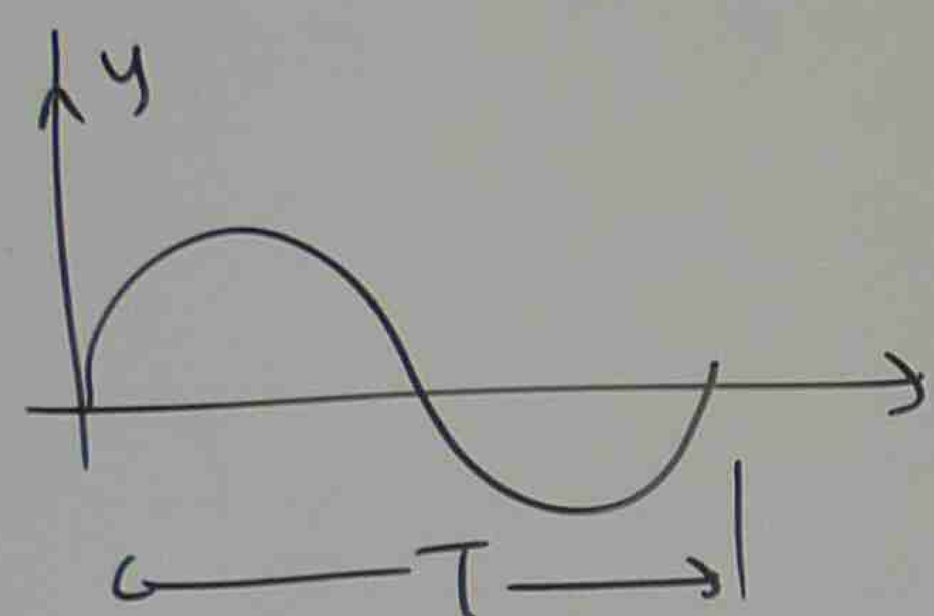
VELO

$K =$ ANGULAR WAVE NUMBER $= \dfrac{2\pi}{\lambda}$

ANGULAR FREQUENCY $= \omega = \dfrac{2\pi}{T}$

FREQUENCY $f = \dfrac{1}{T} = \dfrac{\omega}{2\pi}$

$\lambda =$ WAVE LENGTH, $T =$ PERIOD



THE SPEED OF A TRAVELLING WAVE

$Kx - \omega t =$ CONSTANT

$$v = \frac{\omega}{K} = \frac{\lambda}{T} = \lambda f$$

LINEAR VELOCITY

(d) $y = 0.00327 \sin(72.1x - 2.72t)$

$y = 0.00327 \sin\left(72.1 \times \frac{22.5}{100} - 2.72 \times 18.9\right)$

$= 0.00192\,m \to 1.92\,mm$

Pb A WAVE TRAVELLING ALONG A STRING IS DESCRIBED BY

$y(x,t) = 0.00327 \sin(72.1x - 2.72t)$

(a) WHAT IS THE AMPLITUDE OF THIS WAVE?

(b) WHAT ARE THE WAVE LENGTH, PERIOD AND FREQUENCY OF THIS WAVE?

(c) WHAT IS THE VELOCITY OF THIS WAVE?

(d) WHAT IS THE DISPLACEMENT y AT $x = 22.5\,cm$ AND $t = 18.9$ sec?

(a) $x_m = 0.00327\,m \to 3.27\,mm$ ($\times 1000$)

(b) $y(x,t) = 0.00327 \sin(72.1x - 2.72t)$

$y(x,t) = y_m \sin(kx - \omega t)$

$k = 72.1$ RAD/m, $\omega = 2.72$ RAD/s

$\lambda = \dfrac{2\pi}{k} = \dfrac{2 \times 3.1416}{72.1} = 0.0871\,m \to 8.71\,cm$ ($\times 100$)

$T = \dfrac{2\pi}{\omega} = \dfrac{2 \times 3.1416}{2.72} = 2.31$ sec

$f = \dfrac{1}{T} = \dfrac{1}{2.31} = 0.433$ HZ

(c) $v = \dfrac{\omega}{k} = \dfrac{2.72\,RAD/s}{72.1\,RAD/m} = 0.0377\,m/s$

$x - \omega t)$

AMPLITUDE

AVELENGTH