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Internal Assessment Test 1 – June 2021

Sub:	Engineering Physics Theory					Sub Code:	18PHY22	Branch:	ECE/EEE/ME/CIV
Date:	23-06-2021	Duration:	90 mins	Max Marks:	50	Sem / Sec:	II / I,J,K,L,M,N and O		OBE

Answer any FIVE FULL Questions

Given: $c = 3 \times 10^{8}$ m/s; $h = 6.625 \times 10^{-34}$ Js ; $k = 1.38 \times 10^{-23}$ J/K; $m_e = 9.1 \times 10^{-31}$kg; $e = 1.6 \times 10^{-19}$C

Q. No.	Question	MARKS	CO	RBT
1 (a)	State Heisenberg's uncertainty principle and show that electrons cannot exist in the nucleus.	[07]	CO1	L3
(b)	If the output power of GaAs (E_g = 1.4 eV) semiconductor laser is 5 mW, calculate the number of photons emitted in 10 seconds.	[03]	CO1	L3
2 (a)	Find the eigenfunction and energy eigenvalues for a particle in a one dimensional potential well of infinite height.	[07]	CO3	L3
(b)	A photon of wavelength 1µm is emitted due to a transition between two energy levels in a two-level atomic system at thermal equilibrium. Determine the atomic population of the excited state if 10^{35} atoms are present in the ground state at temperature 300K.	[03]	CO1	L3
3 (a)	Derive time independent Schrodinger wave equation for a particle moving in one dimension.	[07]	CO1	L3
(b)	Discuss the application of lasers in data storage in a compact disc.	[03]	CO1	L2
4 (a)	Obtain an expression for energy density of radiation under thermal equilibrium in terms of Einstein's coefficients.	[06]	CO1	L3
(b)	Calculate the de-Broglie wavelength of a quantum particle of mass $1Gev/c^2$, having energy 1eV.	[04]	CO1	L3
5 (a)	Explain the construction and working of CO_2 laser, with the help of suitable diagrams.	[07]	CO1	L3
(b)	Calculate the energy eigenvalue of an electron in the first excited state of a 1D infinite potential of width $1A^0$.	[03]	CO3	L2
6 (a)	Explain the construction and working of a semiconductor laser, with the aid of suitable diagrams.	[07]	CO1	L3
(b)	Define (i)Acoustic waves (ii)Subsonic waves (iii)Supersonic waves	[03]	CO3	L1
7(a)	A supersonic plane in uniform motion travels 3000 km in two hours. Determine the Mach angle for the plane, if the speed of sound in air is 330 m/s.	[05]	CO3	L4
(b)	Determine the width of a spectral line corresponding to emission of photon of energy 3eV, if the minimum time spent by the electrons in the upper energy state is 1nanosecond.	[05]	CO1	L4
8(a)	Describe the construction and working of Reddy Shock tube with a neat diagram.	[06]	CO3	L3
(b)	The position and momentum of an electron with energy 0.5 keV are determined. What is the minimum percentage uncertainty in its velocity, if the uncertainty in position is $0.5A^0$?	[04]	CO1	L3

IAT-1 EVEN SEM 2020-21

SCHEME

1.a) [7]

HEISENBERG'S UNCERTAINTY PRINCIPLE:

The position and momentum of a particle cannot be determined accurately and simultaneously.The product of uncertainty in the measurement of position (Δx) and momentum (Δp) is always greater than or equal to $\frac{h}{2\Pi}$.**1 Mark**

$$(\Delta x).(\Delta p) \geq \frac{h}{4\Pi} \quad \textbf{1Mark}$$

TO SHOW THAT ELECTRON DOES NOT EXIST INSIDE THE NUCLEUS:

We know that the diameter of the nucleus is of the order of 10^{-14}m.If the electron is to exist inside the nucleus, then the uncertainty in its position Δx cannot exceed the size of the nucleus

$$\Delta x = 5x10^{-15} m$$

Now the uncertainty in momentum is

$$\Delta x = 5x10^{-15} m$$

$$\Delta P = \frac{h}{4\pi x \Delta x} = 0.1x10^{-19} kg.m/s$$

Then the momentum of the electron can atleast be equal to the uncertainty in momentum.

$$P \approx \Delta P = 0.1x10^{-19} kg.m/s$$ **3 Marks**

Now the energy of the electron with this momentum supposed to be present in the nucleus is given by (for small velocities -non-relativistic-case)

$$E = \frac{P^2}{2m} = 548.8x10^{-13} J = 343 MeV$$

. The beta decay experiments have shown that the kinetic energy of the beta particles (electrons) is only a fraction of this energy. This indicates that electrons do not exist within the nucleus. They are produced at the instant of decay of nucleus ($n \rightarrow p + \overset{-}{e} + \nu$ / $p \rightarrow n + \overset{+}{e} + \nu$).**2 Marks**

1.b) [3]

$$E_g = \frac{hc}{\lambda} = 2.24x10^{-19} \text{ J}$$ **1 Marks**

No.of Photons emitted in 10s =

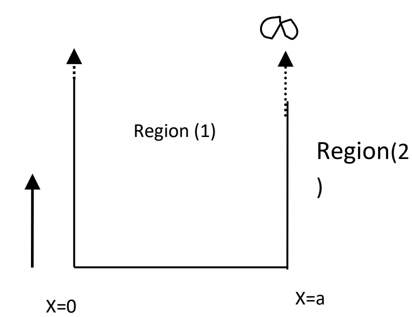
$$n \times 10 = \frac{P}{E} \times 10 = 2.2x10^{17}$$

2Marks

2.a) [7]

Particle in an infinite potential well problem:

Consider a particle of mass m moving along X-axis in the region from X= 0 to X = a in a one dimensional potential well as shown in the diagram. The potential energy is assumed to be zero inside the region and infinite outside the region.



Applying, Schrodingers equation for region (1) as particle is supposed to be present in region (1)

$$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 mE\psi}{h^2} = 0 \because V = 0$$ for region (1)

But $k^2 = \frac{8\Pi^2 mE}{h^2}$

$$\therefore \frac{d^2\Psi}{dx^2} + k^2\Psi = 0$$

Auxiliary equation is $(D^2 + k^2)x = 0$

Roots are D = +ik and D = -ik

The general solution is

$$x = Ae^{ikx} + Be^{-ikx}$$
$$= A(\cos kx + i\sin kx) + B(\cos kx - i\sin kx)$$
$$= (A+B)\cos kx + i(A-B)\sin kx$$
$$= C\cos kx + D\sin kx$$ **2 Marks**

The boundary conditions are

1. At x=0, $\Psi = 0 \therefore C = 0$
2. At x=a, $\Psi = 0$

D sin ka = 0 $\Longrightarrow$ ka = n Π ………(2)

where n = 1, 2 3…

$$\therefore \Psi = D\sin\left(n\frac{\Pi}{a}\right)x$$

From (1) and (2) **Eigen value** E = $\dfrac{n^2h^2}{8ma^2}$ **2 Marks**

To evaluate the constant D:

Normalisation: For one dimension

$$\int_0^a \Psi^2 dx = 1$$

$$\int_0^a D^2 \sin^2(\frac{n\Pi}{a})x dx = 1$$

But $\cos 2\theta = 1 - 2\sin^2\theta$

$$\int_0^a D^2 \frac{1}{2}(1-\cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\int_0^a \frac{D^2}{2}dx - \int_0^a \frac{1}{2}\cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\frac{D^2 a}{2} - \quad [\sin 2\left(\frac{n\Pi}{a}\right)\frac{x}{2}]_0^a = 1$$

$$D^2\frac{a}{2} - 0 = 1$$

D = $\sqrt{\dfrac{2}{a}}$

$$\therefore \Psi_n = \sqrt{\frac{2}{a}}\sin\left(n\frac{\Pi}{a}\right)x$$ **3 Marks**

2.b) [3]

From Boltzmann’slaw,

$$\frac{N_{ground}}{N_{excited}} = e^{\frac{hc}{\lambda kT}}$$

$$N_{excited} = 1.4x10^{14}$$ **(1+2=3 Marks)**

3a) [7]

Time independent Schrödinger equation

A matter wave can be represented in complex form as

$$\Psi = A\sin kx(\cos wt + i\sin wt)$$

$$\Psi = A\sin kx e^{iwt}$$

Differentiating wrt x

$$\frac{d\Psi}{dx} = kA\cos kx e^{iwt}$$

$$\frac{d^2\Psi}{dx^2} = -k^2 A\sin kx e^{iwt} = -k^2\Psi$$ ………….. (1)

From Debroglie’s relation

$$\frac{1}{\lambda} = \frac{h}{mv} = \frac{h}{p}$$

k = $\dfrac{2\pi}{\lambda} = \dfrac{2\Pi p}{h}$

$$k^2 = 4\Pi^2\frac{p^2}{h^2}$$ ……………. (2) **4 Marks**

Total energy of a particle

E = Kinetic energy + Potential Energy

$$E = \frac{p^2}{2m} + V$$

E = $\dfrac{1}{2}$ m v^2 + V

$$p^2 = (E-V)2m$$

Substituting in (2)

$$k^2 = \frac{4\Pi^2(E-V)2m}{h^2}$$

$\therefore$ From (1)

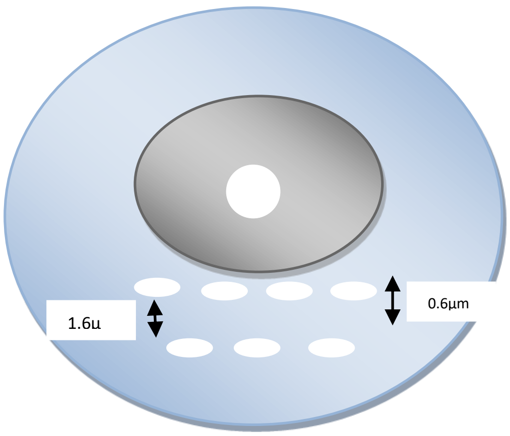
$$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 m(E-V)\Psi}{h^2} = 0$$

3 Marks

3b. [3]

LASERS IN DATA STORAGE

In a compact disc, series of microscopic holes known as pits are formed by burning. Laser light is reflected from the disc surface and is detected by photodiodes. The amount of light received by the diodes varies according to the presence or absence of pits.



In a CD, 1s and 0s are recorded in the form of pits along a spiral track on a plastic material with a metal coating. The total length of the track would be around 6km.Any transition from pit to land or land to pit is read as 1 while the region completely in the land or pit is read as 0.Seperation between tracks is 1.6µm in CD and 1.1µm in a DVD (**DVD DIGITAL VIDEO DISK).**The laser beam is focused on the surface of CD. The reflected beam reaches photodetector and processed. The laser spot should have minimum size. Holographic storage uses entire volume of the recording medium rather than the surface and hence stores large data.

Ex: AlGaInP (640nm) is used to read the data in DVD as it can be focused on a very small region.

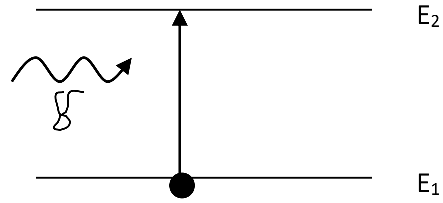
4.a.{7 Marks}

Expression for energy density:

Induced absorption:

It is a process in which an atom at a lower level absorbs a photon to get excited to the higher level.

Let E_1 and E_2 be the energy levels in an atom and N1 and N_2 be the number density in these levels respectively. Let U_γ be the energy density of the radiation incident..



$$\gamma = \frac{E_2 - E_1}{h}$$

Rate of absorption is proportional to the number of atoms in lower state and also on the energy density U_γ.

Rate of absorption = $B_{12}\, N_1 U_\gamma$

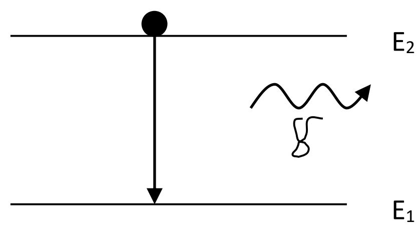
Here B_{12} is a constant known as Einsteins coefficient of spontaneous absorption.**1 Mark**

Spontaneous emission:

It is a process in which ,atoms at the higher level voluntarily get excited emitting a photon. The rate of spontaneous emission representing the number of such deexcitations is proportional to number of atoms in the excited state.

Rate of spontaneous absorption = $A_{21}\, N_2$

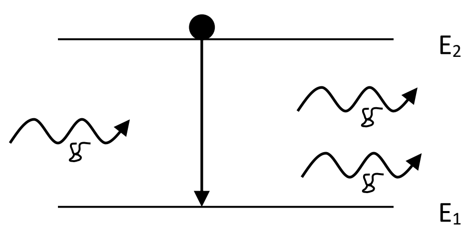
Here B_{12} is a constant known as Einsteins coefficient of spontaneous emission. **1 Mark**



$$\gamma = \frac{E_2 - E_1}{h}$$

Stimulated emission:

In this process, an atom at the excited state gets deexcited in the presence of a photon of same energy as that of difference between the two states.



$$\gamma = \frac{E_2 - E_1}{h}$$

The number of stimulated emissions is proportional to the number of atoms in higher state and also on the energy density U_γ.

Rate of stimulated emission = $B_{21}\, N_2 U_\gamma$

Here B_{21} is the constant known as Einsteins coefficient of stimulated emission.**1 Mark**

At thermal equilibrium,

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$B_{12} N_1 U_\gamma = A_{21} N_2 + B_{21} N_2 U_\gamma$$

$$U_\gamma = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

Rearranging this, we get

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12} N_1}{B_{21} N_2} - 1} \right]$$

From Boltzmanslaw , $\frac{N_1}{N_2} = e^{\frac{h\gamma}{kT}}$

Hence

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} e^{\frac{h\gamma}{kT}} - 1} \right]$$

From Planck's radiation law,

$$U_\gamma = \frac{8\pi h \gamma^3}{c^3} \left[\frac{1}{e^{\left[\frac{h\gamma}{kT}\right]} - 1} \right]$$

Comparing these expressions, we get

$\frac{A_{21}}{B_{21}} = \frac{8\pi h \gamma^3}{c^3}$ and $\frac{B_{12}}{B_{21}} = 1$ **4 Marks**

4b. [3]

$$\lambda = \frac{h}{\sqrt{2mE}}$$

$$m = \frac{1x10^9 x1.6x10^{-19}}{(3x10^8)^2} kg$$

$$E = 1x1.6x10^{-19} J$$

$$\lambda = 0.27x10^{-10} m$$

5.a.{7}

Carbon dioxide laser

Construction

1.Active medium – Mixture of CO_2, N_2 and He in the ratio 1:2:8. Nitrogen absorbs energy from the pumping source efficiently.Helium gas conducts away the heat and also catalyses collisional deexcitation of CO_2 molecules.

2.The discharge tube consists of a glass tube of 10-15mm diameter with a coaxial water cooling jacket.

3.Partially reflecting and fully reflecting mirrors are mounted at the ends of the tube.

4.Optical pumping is achieved by electric discharge caused by applying potential difference of over 1000V.**3 Marks**

Working:

1.CO_2 is a linear molecule and has three modes of vibration –Symmetric stretching (100), Asymmetric stretching (001) and bending (010).

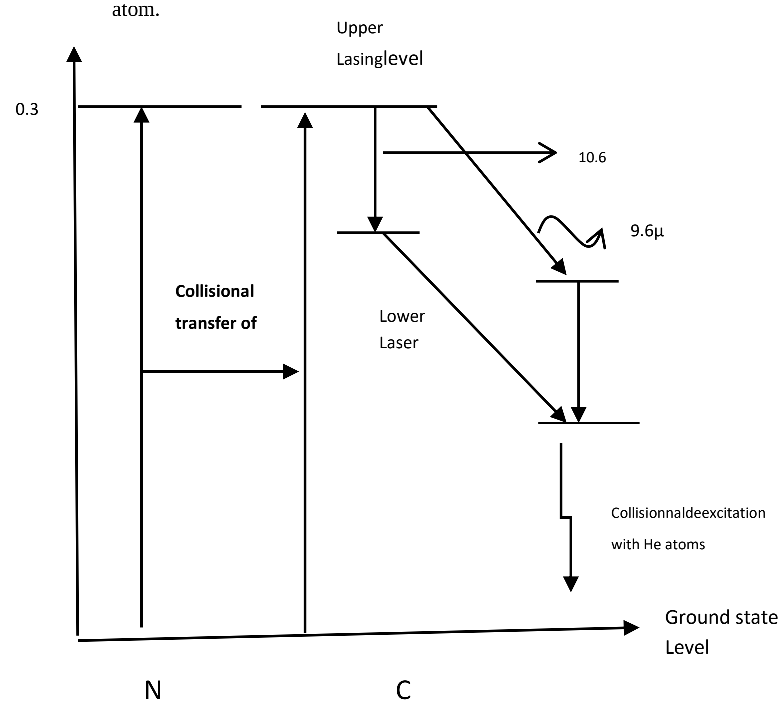
2. Asymmetric stretching (001) is the upper laser level which is a metastable state. (100) and (020) are the lower lasing states

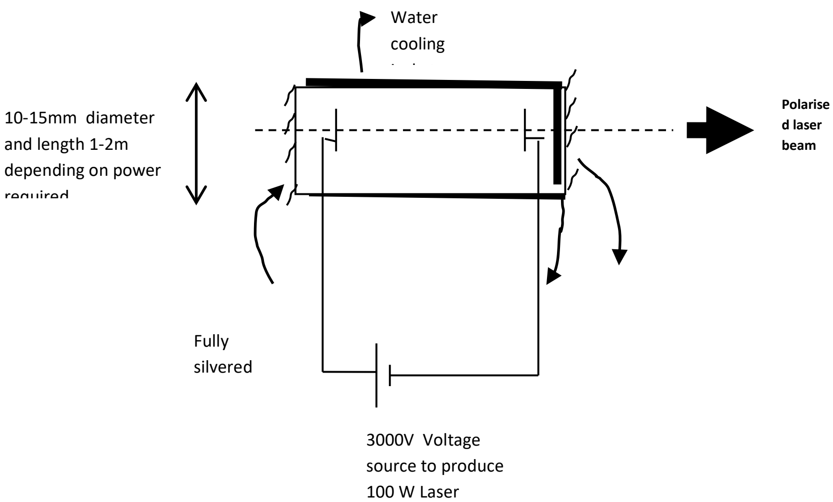
3.During electric discharge, the electrons released due to ionisation excite N_2 molecules to its first vibrational level which is close to upper lasing level of CO_2.

4.N_2 molecules undergo collisions with CO_2 molecules and excite them to (001). This results in population inversion.

5.Lasing transition occurs between (001) and (100) emitting at 10.6µm and (001) to (020) emitting at 9.6µm

6. CO_2 molecules deexcite to ground state through collisions with Helium atom.





Working of CO_2 laser: Diagram 1 mark, Explanation 3 Marks

5.b. [3]

Eigen Value $E = \frac{n^2h^2}{8mL^2}$

1mark

$$E = \frac{n^2h^2}{8mL^2}$$

For L= 1A^0 n = 2

E =24X10^{-18}J= 148eV 2 Marks

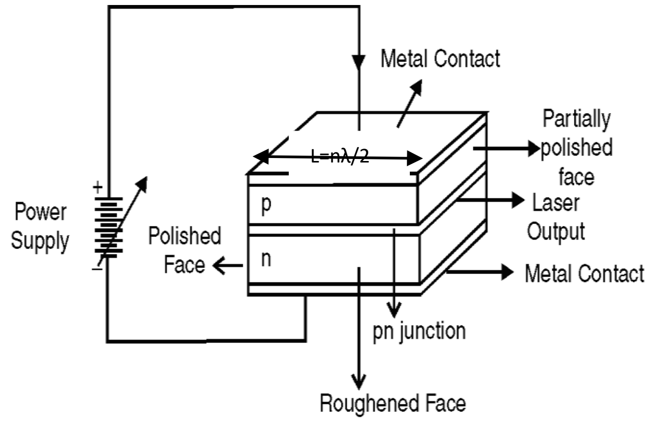
(Formula 1 Mark Substitution andCalculation 2 marks)

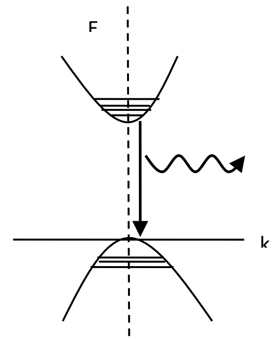
6a [7]

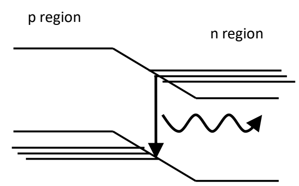
Gallium – Arsenide Semiconductor laser :

It is the only device which can be used for amplification in the infrared and optical ranges.

Amplification is possible if the population of the valence and conduction bands could be inverted as shown in the diagram.







The first laser action was observed in a GaAsjunction(8400Å) which is a direct gap semiconductor.

When a heavily doped junction is forward biased, electrons from n side are injected into p side causing population inversion. They combine with holes on the p side releasing photons. The junction region is the active region .The optical cavity is formed by the faces of the crystal itself which are taken on the cleavage plane and are then polished. The wavelength of the radiation depends on temperature. The wavelength of laser increases as the temperature increases as the energy gap decreases. The frequency can be increased to the optical region by alloying with phosphor according to the relation $Ga(As)_{1-x}P_x$.

If E_g is the energy gap, then $E_g = eV_{forward} = \frac{hc}{\lambda}$

Construction with Diagram 3 Marks

Working with Energy level diagram 4 marks

6b [3]

Acoustic waves:A longitudinal wave that consists of a sequence of pressure pulses propagating in a medium. The speed of an acoustic wave in a material medium is determined by the temperature, pressure, and elastic properties of the medium.

Subsonic waves: These are sound waves with Mach number less than 1. Velocity of the object is less than velocity of sound.

Ex: Low intensity shock waves produced during the motion of ordinary aircrafts.

Super sonic waves: These are shock waves with Mach number greater than 1. Velocity of the object is greater than velocity of sound.

Ex: shock waves produced during the motion of jet planes, bullets etc.

7a. [2+1+2 =5]

$$V_{shock} = \frac{3000000}{2x3600} = 416m/s$$

$$M = \frac{V_{shock}}{V_{sound}} = 1.26$$

$$\theta_{mach\ angle} = \sin^{-1}\left(\frac{1}{M}\right) = 52.4^{o}$$

$$\Delta E.\Delta t = h/4\pi$$

$$\Delta E = \frac{h}{4\pi.\Delta t} = 5.27x10^{-26}J$$

$$E = \frac{hc}{\lambda}$$

7b. *Differentiate*

$$\Delta E = -\frac{hc}{\lambda^2}\Delta\lambda$$

$$\lambda = \frac{hc}{E} = 4130x10^{-10}m$$

$$width\ \Delta\lambda = \frac{\Delta E x \lambda^2}{hc} = 4.5x10^{-14}m$$

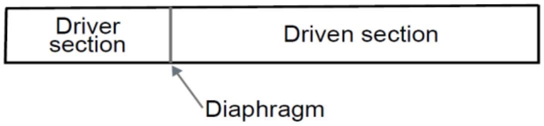
[1+2+2 =5]

8A. [6]

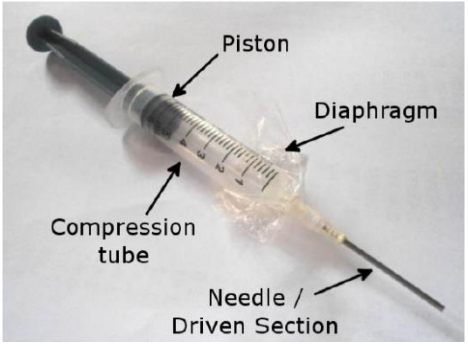
Reddy shock tube:

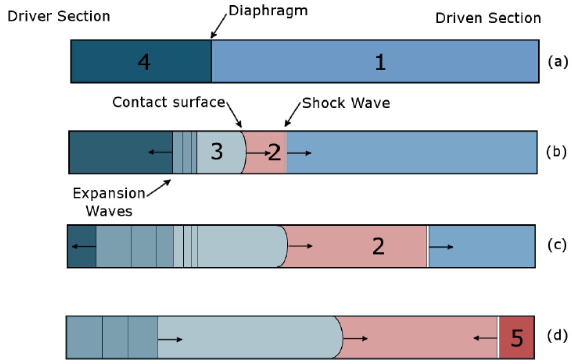
A shock tube is a device used to study the changes in pressure & temperature which occur due to the propagation of a shock wave. A shock wave may be generated by an explosion caused by the buildup of high pressure which causes diaphragm to burst.

It is a hand driven open ended shock tube. It was conceived with a medical syringe. A plastic sheet placed between the plastic syringe part and the needle part constitutes the diaphragm.



- A high pressure (driver) and a low pressure (driven) side separated by a diaphragm.
- When diaphragm ruptures, a shock wave is formed that propagates along the driven section.
- Shock strength is decided by driver to driven pressure ratio, and type of gases used.



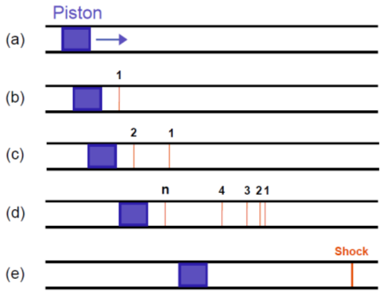


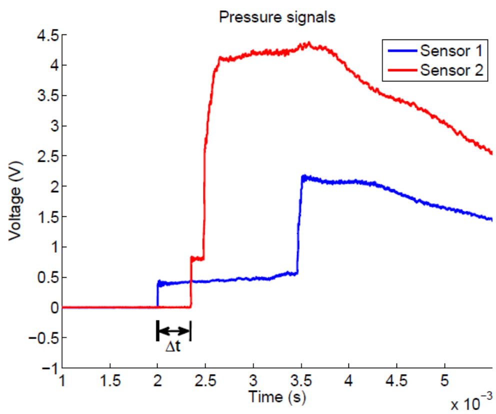
Working:

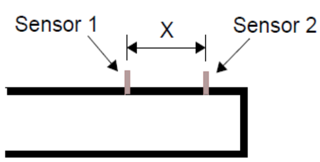
- The piston is initially at rest and accelerated to final velocity V in a short time t.
- The piston compresses the air in the compression tube. At high pressure, the diaphragm ruptures and the shock wave is set up. For a shock wave to form, $V_{piston} > V_{sound}$.

  Formation of shock wave:

  As the piston gains speed, compression waves are set up. Such compression waves increase in number. As the piston travels a distance, all the compression waves coalesce and a single shock wave is formed. This wave ruptures the diaphragm.







$$U_s = \frac{X}{\Delta t}$$

8B **[1+2+1= 4]**

$$p = \sqrt{2mE} = 1.2x10^{-23} kgm/s$$

$$\Delta p = \frac{h}{4\pi.\Delta x} = 1.05x10^{-24} kgm/s$$

$$(\Delta p/p)100 = 8.7\%$$