CONTENT ENRICHMENT TRAINING PROGRAMME IN PHYSICS FOR JUNIOR COLLEGE LECTURERS OF APSWREI, HYDERABAD

(22.6.1998 to 3.7.1998)

Regional Institute of Education, Mysore 570 006

[National Council of Educational Research and Training, New Delhi]

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RIE FACULTY

Dr S S Raghavan (Coordinator)
Dr P R Lalitha
Dr R Narayanan
Mr P R Rao

Regional Institute of Education, Mysore 570 006
[National Council of Educational Research and Training, New Delhi]

Introduction

A twelve day training programme in Physics, for the Junior College Lecturers, who are working in the APSWREI Society run institutions, was conducted at the Regional Institute of Education, Mysore from 22nd June to 3rd July 1998. This programme was initiated at the request of the APSWREI Society, Hyderabad and was fully funded by it. Two weeks training schedule was planned tentaively and finalised after discussions with the participants (Annexure I). Twenty seven Junior College lecturers from several colleges attended the training programme (Annexure II). The resource persons for this programme were drawn from the physics faculty of the Regional Institute of Education, Mysore, including the former member of the Physics faculty. (Annexure III).

About the Training

On the first morning session of the programme, the resource persons had a detailed discussions with the participants. During this session, the teachers identified the following topics from the first and second year of the intermediate courses, for an indepth discussion by the resource persons :

- i) Rotatory and circular motions
- ii) Thermodynamics
- iii) Thermoelectricity
- iv) Electromagnetism
- v) Waves and oscillations
- vi) Solid State Physics and Semiconductors
- vii) Nuclear Physics

Based on the above broad topics suggested by the participating teachers, the resource persons identified the "hard-spots" of the teachers. These were then taken up for lecture-cum-demonstration-cum-discussion sessions. The theory sessions, which were divided into two one and a half hour sessions during the mornings, were designed in such a way that the teachers actively participated in the sessions. The topics identified by the resource persons were introduced to the participants through various activities. The teaching of science (particularly physics here) should be actively based, wherever possible, was illustrated through a variety of examples.

Two sessions were also devoted to the theories of learning. It was pointed out to the participants that the emphasis has to shift from covering the syllabus, to students learning. Teaching is for learning which is a student activity and the teachers' role is one of the guidance. In order that the knowledge is retained by the students over a longer period of time, it is necessary to attempt to teach for understanding rather than developing abilities to recall the content previously learnt, the teachers were told. It was emphasised that the teaching must result in mental development leading to comprehension of knowledge imparted. Some handouts on theory lessons were given to each participant.

The afternoon sessions of the training programme were held in the physics laboratory of the institute, where the teachers performed some experiments. A set of ten experiments relating to topics from Mechanics to Nuclear Physics were arranged in the laboratory. All the participants did each of these experiments and were supervised by the resource persons. Writeup for all these experiments was given to the teachers for reference.

Basic concepts in Mechanics were introduced through a set of experiments, such as measuring the acceleration of bodies, studying the conservation of momentum in head-on collisions and in mechanical explosions. An experiment to study Newton's second law of motion enabled the participants to study the law in detail. The teachers enjoyed in performing these experiments since they could be replicated in their institutions and they illustrate various concepts in a simple way.

Concepts of interference and diffraction were illustrated in the laboratory through experiments in optics and laser. Other experiments performed by the teachers included the characteristics of junction (Zener) diodes, the use of Geiger-Muller counters in detecting nuclear radiations and the determination of energy gap in semiconductors. The above mentioned experiments were set up to enrich the content knowledge of the teachers. The laboratory writeups are enclosed with this report.

In addition to the laboratory sessions, there were exclusive experimental demonstration sessions organised by the resource persons. The discharge of electricity through gases using a discharge tube and the formation of water waves and the related studies using a ripple tank were demonstrated. The participating teachers were also exposed to the use of computers in education. In addition, video lessons on some topics related to physics were presented.

At the end of the twelve day programme, the teachers were of the opinion, that their knowledge in content was enriched and they acquired some skills in the method of teaching physics to young learners.

Annexure I

Training Schedule

22.6.98 to 3.7.98

DATE/DAY	I SESSION 9.30 AM TO 11 AM	II SESSION 11.15 AM TO 12.45 PM		III SESSION 2 PM TO 3.30 PM	IV SESSION 3.30 PM TO 5 PM
22.6.98 (Monday)	Registration	Interaction with participants		Lab Session I (SSR + RN)	
23.6.98 (Tuesday)	Theory I SSR (1)	Theory II PRR (1)		Lab Session II (PRR + SSR)	
24.6.98 (Wednesday)	Theory III RN (1)	Theory IV PRR (2)		Demonstration – I (RN + PRL)	
25.6.98 (Thursday)	Theory V PRL (1)	Theory VI PRR (3)		Lab Session III (PRR + PRL)	
26.6.98 (Friday)	Theory VII RN (2)	Theory VIII SSR (2)		Lab Session IV (RN + PRR)	
27.6.98 (Saturday)	Theory IX SSR (3)	Theory X RN (3)		Lab Session V (SSR + RN)	
28.6.98 (Sunday)	PROJECT WORK				
29.6.98 (Monday)	Theory XI PRL (2)	Theory XII PRR (4)		Lab Session VI (PRR + PRL)	
30.6.98 (Tuesday)	Theory XIII RN (4)	Theory XIV SSR (4)		Lab Session VII (SSR + PRR)	
1.7.98 (Wednesday)	Theory XV PRL (3)	Theory XVI SSR (5)		Lab Session VIII (PRL + RN)	
2.7.98 (Thursday)	Theory XVII PRL (4)	Theory XVIII RN (5)		Lab Session IX (PRL + SSR)	
3.7.98 (Friday)	Theory XIX PRR (5)	Theory XX PRL (5)		General Discussion	

Annexure II

CONTENT ENRICHMENT COURSE IN PHYSICS FOR THE JUNIOR LECTURERS OF APSWREIS

List of Participants

1. Appa Rao Bammidi
   APSWR Junior College
   Kanchili (via)
   Srikakulam Dt
   AP 532 290

2. V L Narasimha Rao Kolluru
   APSWR Junior College
   Devarapally
   Visakapatnam Dt, AP

3. V V Krishna Rao
   APSWR Junior College
   Karempudi, Guntur Dt
   AP 522 614

4. B V Poornachandra Rao
   APSWR Junior College
   Badangi, Vizianagaram Dt
   AP

5. D Udaya Bhaskar
   APSWR Junior College
   Kurnool 518 002, AP

6. M Vijaya Bhaskara Reddy
   Dr BRACSWR Junior College
   L N Puram, East Godavari Dist
   AP 533 342

7. B Mallikarjuna Goud
   APSWR Junior College
   Malugur, Hindupur Tq
   Anantapur Dist, AP 515212

8. V B Subrahmanya Prasad Vermuri
   APSWR Junior College
   Atchampet, Guntur Dist, AP 522409

9. Rupa Devi Pandurangi
APSWR Junior College (G)
Adilabad, AP 504 001

10. B Anna Purna Sarada
APSWR Junior College (G)
L N Colony, Chittoor, AP

11. K Sowbhagya Lakshmi
APSWR Junior College
Koilakuntla, Kurnool Dist, AP

12. V B Kasibhatta
APSWR Junior College
Chimakurthy 523 226
Prakasam Dist, AP

13. Padmavathi Muktevi
APSWR Junior College
Polasanipalli, WG Dist
AP 534 425

14. A Sarada Kalyani
APSWR Junior College (G)
Pedapavani, Lingasamudram Mandal
Prakasam Dist, AP 522 439

15. S Padmaja
APSWER Junior College (G)
Cheepurapalli
Vizianagaram Dist, AP

16. R Ramakrishna
APSWER Junior College
Golugonda, Visakar Dist, AP

17. S Satyavathi
APSWRS Junior College
Mannanur, Mahabubnagar Dist, AP

18. A Sreenivasa Rao
APSWR Junior College
Naidupeta, Nellor Dist, AP

19. P B Sandhyasri
APSWR Junior College, Ameenpet
Eluni, West Godavari Dist, AP

20. K Ranganayaki Rohini (Nandini)
Dr BRACSWR Junior College
Etcherla, Srikakulam Dist
AP 532 402

21. K Koteswara Rao
APSWR Junior College
Duppalavalasa, Srikakulam Dist, AP

22. Shaik Ibrahim
APSWR Junior College
Chillakur 524 412, Nellore Dist, AP

23. K Ranganayaki Rohini (Nandini)
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Ramapuram Mandal
Cuddapah Dist, AP 516 504

27. M Lakshmi Rajyam
APSWR Junior College
Muthukur, Nellore, AP

28. Y N Varmacharyulu
APSWR Junior College, ARUGOLANU PO
T P Gudem Mandal, West Godavari Dist
AP

29. O J Jagadeesh Kumar
APSWR Junior College
Koppula, Vizianagaram Dist
AP 537 255

30. S Sridevi
APSWRS Junior College
Srikalhasti
Chittoor Dist,
AP 517 644

Annexure III

List of Resource Faculty

1.	Dr S S Raghavan Reader in Physics DESM, RIEM	Academic Coordinator
2.	Dr P R Lalitha Reader in Physics DESM, RIEM	Resource Person
3.	Dr R Narayanan Reader in Physics DESM, RIEM	Resource Person
4.	Mr P R Rao Reader in Physics (Retd) DESM, RIEM	Resource Person

Annexure IV

Observations and Suggestions for monitoring the Training Programme

It was felt that the future training programmes should have both content and methodology built into them. The trainers should be told that as far as possible, concepts should be introduced through a variety of activities. Activities such as preparation of models, working demonstrations, charts and audio/video presentations should be given due importance in the training so that the same can be carried out at the college level. Further, atleast some experiments have to be performed by the students to understand the concepts. In this sense some of our suggested experiments can be easily introduced in the colleges. Hence it was felt that laboratory sessions should also be given equal importance in the training programmes.

In the physics group, we have identified the following five teachers who could be used by the Society for conducting further training programmes

i) Mr V V Krishna Rao
APSWR Junior College
Karempudi, Guntur Dt
AP 522 614

ii) Mr D Udhaya Bhaskar
APSWR Junior College
Kurnool 518 002, AP

iii) Mr B Sreeenivasa Rao
APSWR Junior College
Naidupeta, Nellor Dist, AP

iv) Mrs K R Rohini
Dr BRACSWR Junior College
Etcherla, Srikakulam Dist
AP 532 402

v) Mr Shaik Ibrahim
APSWR Junior College
Chillakur 524 412, Nellore Dist, AP

Ann IV ; Material distributed

STUDY OF THE NEWTON'S SECOND LAW OF MOTION

What causes acceleration of bodies ?

What are the factors on which acceleration depend ? how ?

Aim: In this experiment, we shall study the variation of the acceleration 'a' of a body with its mass under a constant force'F'.

Apparatus: Dynamic cart, level table pulleys, stop watch etc. Draw a diagram of the set up.

Procedure

Load the cart with some weights so that the mass of the system (cart + scale pan + weight placed on the cart) is adjusted to nearest hundred - say 1300g. Let it be m. Keep it at a distance of 1.00 m from the bumper. Give a gentle push to the cart and observe its motion. Account for your observation. How will you compensate for frictional force ? Transfer some small weights from the cart to the scale pan, till given a slight push, the cart moves with uniform velocity, as judged by our senses. This compensates the frictional force acting on the cart.

How will you make the cart to accelerate ?

Now transfer a weight of 20g from the cart to the scale pan. This acts as the unbalanced force. How will you measure acceleration ?

Measurement of Acceleration

If S is the distance travelled by a body of mass 'm' in t second, then $S = ut + 1/2\ at^2$, where 'u' is its initial velocity and 'a' is its uniform acceleration. If u = 0, then,

$S = 1/2\ at^2$ *and*

$a = 2S/t^2$

t is the time taken by the body starting from rest to travel a distance S.

Release the cart from a distance of 1m from the bumper and start the stop watch simultaneously. When the cart strikes the bumper, stop the watch.

Note down the time required by the cart to cover a distance of 1.00 m. Repeat this and calculate the average time 't' and hence the acceleration 'a'.

Now repeat the experiment and calculate 'a' when the mass of the system is 1.25M, 1.50M, 1.75M and 2.00M. The unbalanced force is kept same throughout.

***Remember:** when the mass is changed transferring 20g and back to the cart from the scale pan, first see that the* *frictional force are overcome by transferring the weights from the cart to the scale pan. Now given a push, the cart is moving with constant speed. Them measure acceleration by transferring 20g back from the cart to the scale pan.*

How does 'a' vary with the mass of the system when the force is constant ? What proportionality is excepted ? Draw a graph to verify the proportionality so that linear relation is obtained. What graph will you draw ? What is the nature of the graph ? Interpret.

Inference:

Formulation of Newton's law

Combine with the results of the other experiment to get the law, which is known as Newton's second law of motion.

Observation

Mass of the cart =

Mass on the cart =

Mass of the scale pan including the weights in it =

Mass of the system = M ....Kg

S = distance travelled = 1.00m

Sl. No.	Mass of the the system (M)(kg)	Time taken to cover 1.00m(t)S 1	2	3	4	5	Average of best three readings	$a = 2S/t^2$ (ms^{-2})
1	M							
2	M + 200							
3	M + 400							
4	M + 600							
5	M + 800							

Discussion: (i) Offer explanation for discrepancies

(ii) Sources of error and methods to eliminate or minimise

Reference: General Physics - Blackwood and Kelley

GALILEO'S EXPERIMENT

Set up: *Keep the grooved track (about 2.5m long) on a horizontal surface. Place the given smooth ball on it. Lift one end of the track till the ball slides off. Lift a little bit up and fix. (Give reason for this initial adjustment). Make sure that the track does not sag under its own weight. Provide suitable supports to ensure that the track is straight and inclined to the horizontal.*

Step 1: Observation

Release the given smooth polished steel ball about 1cm in diameter from one end marked as starting point. Watch its motion (Judge the pitch of the sound)> what do you guess about the speed of the ball with respect to (a) time of travel and (b) distance travelled ? What type of motion is it ? Write down your guesses.

Step II: Guesses

Step III: *How is acceleration defined ? Can we use this definition for our investigation? Give reason. A more* convenient relation is needed. It could be worked out mathematically. Assuming the motion to be of uniform acceleration, we can derive the equation connecting distance travelled with time [your guess (a) above in step 1]. What is that expression?

Suppose we set the initial velocity to be zero, then

$$S = \frac{1}{2} at^2 \quad \text{or} \quad \frac{S}{t^2} = \frac{a}{2} = \text{constant.}$$

Here, we have a definition for a uniformlly accelerated motion, more suitable for practical work. Distance-square of time graph is a straight line. Is this definition more convenient for practical investigation ? Why?

Step IV : Experimentation

a) Designing and Collection of Data

From the starting point, mark off distance S = 1.00mm, 1.25m, 1.50m, 1.75m, 2.00m and 2.50m (Mark your own tabulation). Measure the time (as average of best three readings, out of about five) taken to travel each distance. Tabulate.

b) Analysis of Data Collected and Drawing Conclusion:

Draw S-t^2 graph and conclude. What does the slope of the graph indicate? What is the acceleration for this inclination?

Step V: Further Questions and Investigation:

i) Draw S-t graph. What does this indicate?

ii) State the relation between speed and distance travelled in [your guess (b) in Step1] the case of a uniformly accelerated motion. Why is speed as a function of distance travelled not suitable for investigation?

iii) List further investigations that one can undertake with this set up?

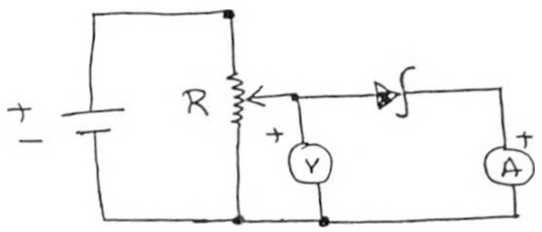
iv) Considering the forces acting on the sphere, calculate the acceleration ?

Ref: Project physics Harvard.

ZENER DIODE

APPARATUS

Diode OA81 or equivalent 1.5 V battery, 500 Ohm potentiometer, 0-15 V meter, 0-10 mA meter (forward and reverse bias).



METHOD

1. Connect up the circuit shown in Figure 1 (forward bias). B is the battery, R is the potentiometer, D is the diode in forward bias, A is the current meter V is the voltmeter. (Care Read the manufacture's catalogue for the maximum voltage and current in forward bias, so as not to damage the diode)

2. Set the potentiometer R so that the voltage in V and the current in A are zero. Adjust R so that the voltage V increases in suitable small steps such as 0.2 V from zero to the maximum such as 1V.

3. Reverse the diode D in the circuit. Record the value of I at a reverse voltage of 1V.

MEASUREMENT

Forward bias

Voltage V/V	Current I/mA

Reverse bias At 1V current I = •• μA

GRAPH

Plot a graph of I against V for forward bias. On the same axes, using negative values for I and I indicate roughly the small current for the reverse for the reverse bias of IV and the form of the graph for reverse bias.

CALCULATION

Using the graph of forward bias (Figure 2) calculate (i) the reciprocal $\Delta V/\Delta I$, of the gradient of the graph at I = 0.7V (This gives the a.c resistance of the diode at this voltage) and (ii) the ratio V/I at I = 0.7V. the d.c resistance at this voltage

a.c. resistance at 0.7 V = Ohm

d.c. resistance at 0.7 V = Ohm

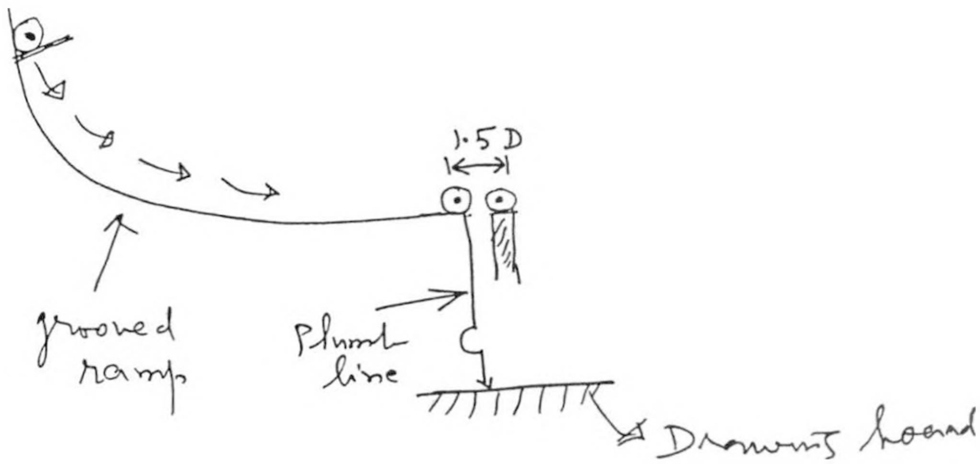
CONCLUSION

Discuss the resistance of the junction diode in forward and reverse bias and whether the diode is an 'ohmic' or 'non-ohmic' component.

CONSERVATION OF MOMENTUM AND KINETIC ENERGY IN A COLLISION OF TWO HARD SPHERES HEAD-ON OR IN ONE-DIMENSION

Set up Draw the diagram and label the parts

Adjustments



i) Adjust the height of the set screw so that its tip is at the same level as the ramp and also along the same line as the groove on the ramp.

ii) Adjust the distance between the edge of the ramp and centre of the set screw to be 1.5D where D is the diameter of any hard sphere.

Observation

Keep the target sphere T on the set screw. Place the bullet sphere B at a suitable location (25cm) of the ramp *with the help of a small scale held vertically. Release the bullet B.*

Record your Observation

Answer the following question:

1. *What is momentum (represent by $\overline{p}$) ?*
2. *What type of physical quantity it is ?*
3. *What physical quantities are to be measured to calculate momentum ?*
4. *What are transferred to sphere T by sphere B during the collision. What happens to the bullet sphere after collision?*
5. *What is the initial momentum of sphere B, sphere T and of the system before collision?*
6. *What is the final momentum of sphere B, sphere T of the system after collision?*

How do you measure the momentum of sphere B, before collision and sphere T after collision ? Stop watch is not given.

What observed and measurable physical quantity can be considered as a measure of momentum? (Hint: Horizontally projected body).

What is range R basically a measure of ?

What other quantity it can represent assuming masses of spheres B and T as same. Similarly, what does R^2 represent?

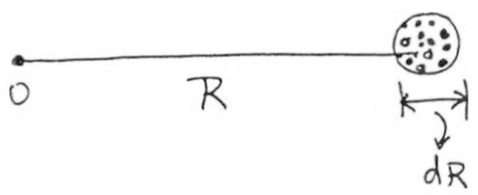
Measurement

Place a carbon paper with carbon side up and place over it a tracing paper. Fix them to the drawing board.

Step 1

Release the bullet sphere B from a suitable position (25cm) on the ramp. Note the position where target sphere exists the tracing paper. Release the sphere from the same point several times and note the distribution of points on the tracing paper.

To what degree is the velocity of the target sphere, after collision always same ?



Step 2

Bring down the set screw so that when sphere B is released from the same point as in step 1 moves down with out hitting the set screw.

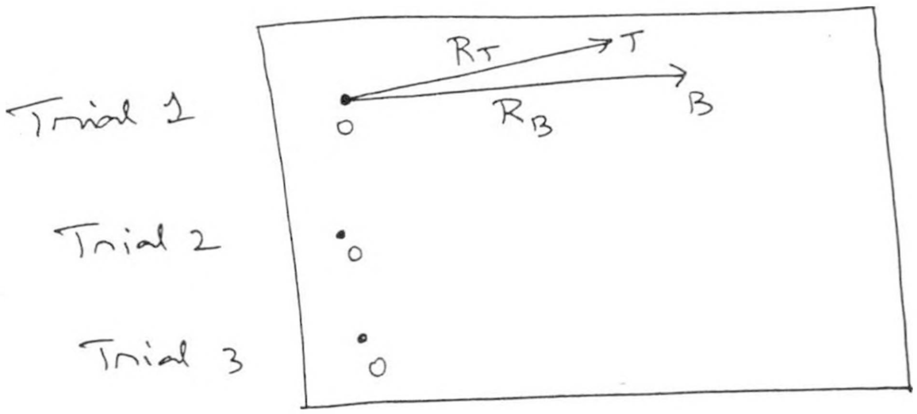
Get the trace for several releases.

To what degree is the initial velocity always the same?

Mark the point "O" corresponding to the tip of the plumb line.

Draw momentum vectors OT and OB. Compare them.

Calculate R^2B and R^2T. Compare them.



Step 3

Repeat, by reloading the bullet sphere from two other positions.

Step 4

Tabulate your measurements

Conclusions:

i) Momentum

ii) Kinetic Energy

Step 5

Discussion:

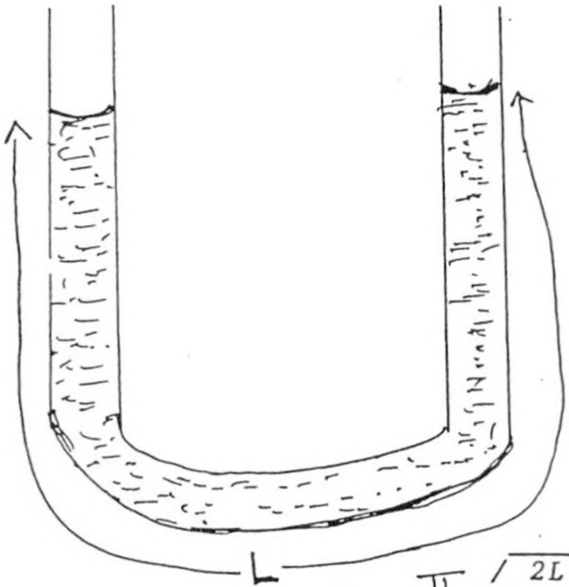
1. Offer explanation for discrepancies, if any

2. Sources of error and Methods to eliminate/minimize

Reference: PSSC Text, Lab guide and Teacher's guide.

SIMPLE HARMONIC MOTION OF LIQUID COLUMN

Take a transparent U-tube containing water. Depress the water level in one side by blowing air. The level of the water on each side oscillates. The oscillation is simple harmonic with time period.



$$T = \pi \sqrt{\frac{2L}{g}}$$

where L is the total length of the after column in the tube and g is the gravitational field strength.

Change L in steps of at least 25cm. To change L, in the beginning itself, from a fixed point such as A, draw marks B,C,D,E,....etc, corresponding to lengths 2.00m, 2.25m, 22.50m, 2.75m, etc. Measure the time period T for different values of L and tabulate the data as shown.

t, Time/in S				Time
Trial 1	Trail 2	Trail 3	Mean t	Period $T=t/n(s)$

Sl. No.	Length of the water *L in m	$\sqrt{L}$	No. of oscillations
1.			
2.			
3.			
4.			
Total			

Plot t versus $\sqrt{L}$

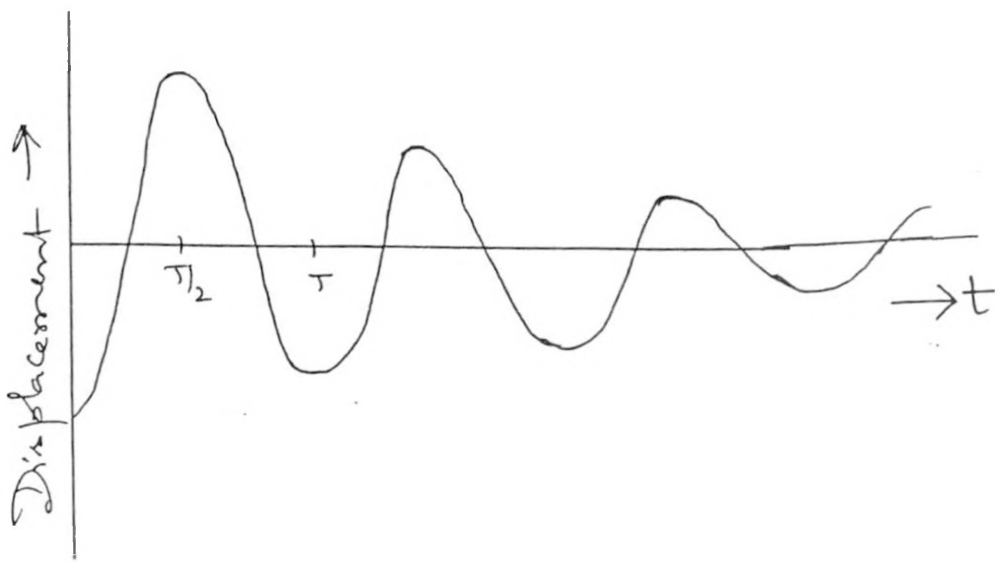
Calculate the slope of the above graph and hence calculate the value of g.

Comment on the result.

For one value of L, the length of the water column, note down the maximum displacements of the water level (both up and down) for the successive oscillations(the amplitude of oscillations goes on decreasing due to damping). With the help of these readings and the time period (T), show graphically the damped harmonic motion plotted against time (see the figure).

What is the locus of successive amplitudes on one side?

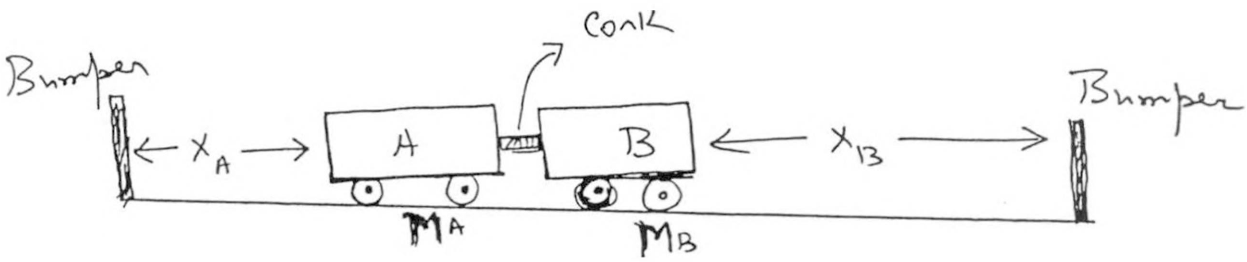
What are the reasons for the decrease in amplitude?



CONSERVATION OF LINEAR MOMENTUM

IN A MECHANICAL EXPLOSION

1. Define Linear Momentum ? What type of physical quantity it is ? (Represented by $\overline{p}$)
2. To measure momentum, what physical quantities need to be measured ?
3. **Set up : Description**



4. What is the total momentum of the system before explosion? (pi_A pi_B and vector sum of these two) (p_i initial momentum).
5. Bring out explosion-describe your observation. What is the total momentum of the system after explosion? Assume V_A and V_B are the velocities respectively.
6. How do you measure V_A and V_B? (Hint:Define velocity). If X_A and X_B are the distances travelled and t_A and t_B are the time taken what is V_A? V_B? p_{fa}? p_{fb}? (p_f - final momentum).
7. Stop watch is not given. Can you set $t_A = t_B$? How? (By adjustment. Arrange the position of system is such a way

that they travel after explosion and hit the respective bumpers at the same instant as heard by the sounds produced).

Then $V_A \propto X_A$ and $V_B \propto X_B$ or $V_A/V_B=$

Measure X_A and X_B (three trials, in one trial carts may be interchanged).

8. What are p_{fA} and p_{fB}? and their ratio?

   Find the vector sum $(\overline{p}_{fA} + \overline{p}_{fB})$?

9. Load both the carts with weights, 200g, 400g, and 800g and repeat.

10. Tabulate.

11. Find the relation between the total momentum of the system before explosion and total momentum of the system after explosion.

12. Calculate the percentage of error as a fraction of the final momentum of cart A.

13. Discuss the sources of error and suggest methods to minimize/eliminate the same.

Sources of Error	Procedure to minimize/elimination

14. In step (9), we suggested the equal loading of both carts. Can we not load only one cart proceed with the experiment? Is momentum conserved in this case too? Calculate percentage error. If more, give reason (Hint: Compare the frictional forces on cart A and cart B in this case). Repeat with 800g on B. Compare X_A and X_B. Write the relation between X_A, X_B, M_A and M_B.

WAVELENGTH OF LIGHT, USING DIFFRACTION GRATING-MINIMUM DEVIATION METHOD

Apparatus: *Spectrometer, Diffraction grating, Sodium vapour lamp (or Hg vapour lamp with green filter). Magnifying glass, spirit level, Incandescent lamp.*

METHOD

1. Carry out the initial adjustments of the spectrometer.

2. Turn prism table so that the ruled side of the grating faces the collimator and is approximately normal to its axis.

3. Bring the collimator and the telescope in a line, so as to se the image of the slit directly, Narrow down the slit as much as possible and make the vertical cross-write of the telescope coincide with the image of the slit. Read the position of the telescope.

4. Locate the first diffracted image, say on the left, with the unaided eye, widening the slit if necessary, Rotate the prism table only without distributing the position of the verniers, towards the left, i.e the same direction in which the eye was moved, keeping the first order image always in sight. At first the direction of motion of the image will be opposite to the direction of rotation of the prism table. Soon a position will be reached when the image becomes stationary for a moment and reverses the direction of motion, although the prism table is steadily rotated int he same direction. Stop rotation of *the table when the image is on the point of reversing its direction of motion. Bring round the telescope. Working on the tangent screw adjust the telescope so that no rotating the prism table the image just comes into coincidence with the vertical cross-wire and then reverse its path. The grating now is in the position of minimum deviation. Read the position of the telescope. The angle through which it had been rotated from its position in (3), is the angle of minimum deviation for the order image. If the grating resolves the Na, light into its components* D_1 *and* D_2 *find the angle of minimum deviation for each of the components.*

5. Set the grating as in(2).After widening the slit if necessary locate the first order image on the right, with the unaided eye. Repeat manipulation in (4) rotating the prism table steadily to the right instead of to the left. Record positions of the telescope when set on images on the point of retracting their paths.

6. Set grating as in(2) again, and repeat (3) to ensure that direct reading of the telescope continues to be the same. Deduce angles of minimum deviation for first order images on the right.

7. Repeat manipulations in (3),(4), (5) and (6) with the second order images on both sides.

8. Record readings as under and calculate # from

$$= \frac{2 \sin \theta/2}{Nn}$$

where θ *is the angle of minimum deviation of the n the order image.*

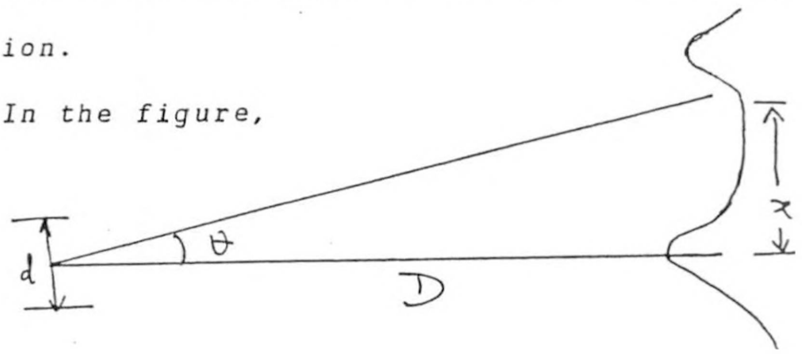
No. of lines per inch =   No. of lines per cm = N

Order of Spectrum n	Position of Telescope — Vernier A: Direct Left	Direct Right	On Spectrum Left	On Spectrum Right	θ	Position of Telescope — Vernier B: Direct Left	Direct Right	On Spectrum Left	On Spectrum Right	θ	θ(mean)	$\lambda = \frac{2 \sin \theta/2}{Nn}$	λ(mean)
I D_1													
I D_2													
II D_1													
II D_2													

DIFFRACTION OF LASER BEAM

AIM: *To find the wavelength of the Laser beam by means of diffraction.*

THEORY: *In the figure,*



a light beam passes through the slit of width 'd' and a diffraction pattern is formed on the screen. The distance between the slit and the screen is D. The separation between the I_{max} and I_{min} is x.

The condition for getting a maxima is given by

$d\sin\theta = n\lambda$ where n = order

From the figure, $\tan\theta = \frac{x}{D}$

$d\sin\theta = n\lambda$ becomes $\theta \simeq \sin\theta \approx \tan\theta$ (θ is small)

$d\theta = n\lambda$

$d\tan\theta = n\lambda$

$$\frac{dx}{D} = n\lambda$$

$$\lambda = \frac{xd}{nD}$$

If the diffraction pattern is of order 1, then, $\lambda = \frac{xd}{D}$

where

d = slit width

D = distance between paper and slit

x = distance between centre of the max and centre of the corresponding (order) minima

Discussion: *As we move away from the central max the intensity of the beam decreases. As the slit width is increased, the diffraction pattern gets disturbed.*

ABSORPTION COEFFICIENT OF GAMMA RAYS

AIM: *To determine the absorption coefficient of gamma rays using a G.M counter.*

APPARATUS REQUIRED *G.M. Counter, G.M. Tube, source, absorber of different thickness.*

PROCEDURE: *The G.M. Counter is fixed on a stand on which the source can be kept at a definite distance from the counter window. On the stand there are two lead shields (2-3 cm thick) with a circular hole at their centre 1 to condense the radiation to the counter window.*

The G.M. Counter is converted to an electrical circuit. The instrument is switched on and it is allowed it stabilise for about 15 min. Without any the gamma ray source and lead plates, the background Counts (b_1) are noted for 2 minutes before starting the experiment.

Similarly, just after the experiment also the background Counts(b_2) for 2 minutes are noted and the mean background Count for a minute (h) is calculated as

$$b = \frac{b_1 + b_2}{4}$$

Trial No.	Thickness of lead fitter t(cm)	Observed count for 2min	Observed count per min(N^1)	Gross Counts per min ($N=N^1-b$)	Error $E= \pm\sqrt{N}$	log (N+E)	log (N-E)
1							
2							
3							
4							
5							

Slope = cm^{-1} μ = cm^{-1}

The gamma ray source is then placed on the stand in front of the counter at the central hole of the lead shield. A lead plate of thickness (t cm) is conduced in between the source and the counter window. The number of counts registered by the instrument for 2 minutes is recorded and the count rate per minute (N') is determined.

The experiment is repeated with different lead plates (of increasing thickness) in between, the gamma ray source and the counter window. The results are tabulated and in each case the gross count rate per minute is determined.

$$N = N' - b$$

A graph is drawn with thickness (t cm of the plated by the X-axis and the corresponding values of log ($N \pm E$) by the Y-axis and E is error ($E = \pm \sqrt{N}$). The resulting graph will be a straight line. The slope of the graph is determined.

$$\therefore \quad \mu = \frac{\text{slope}}{0.4343}$$

ENERGY GAP OF A SEMICONDUCTOR

AIM: *To find the energy band gap of a semi-conductor by finding the resistance variation with temperature.*

APPARATUS: *Meterbridge, Galvanometer, Cell, Resistance box, Beaker, Semiconductor, Thermometer.*

THEORY:

The e^- in the crystal are arranged in energy bands separated by regions in energy for which no waveline orbitals exist. Such forbidden regions are called energy gaps or forbidden gap. In a semiconductor crystal all the bands are filled except for one or two bands which are slightly filled.

At absolute zero, a semiconductor would be almost like an insulator. As time is increased, e^- are thermally excited from the valence to the conduction band and results in the decrease of resistance.

Left E be the energy of the electron corresponding to the top of the valence band and E_c be the energy corresponding to the bottom of the conduction band. Making use of fermi distribution function $F(E)$, it can be show that

$$E_f = 1/2[E + E_c]$$

where, E_f = Fermi energy which lies halfway between the top of the valence band and bottom of the conduction band.

In an intrinsic semiconductor, a number of conductivity e^- with effective density (n) of the available states in conduction band is shown as

$$n \propto e^{(E_f - E_c)/K^t}$$

At any temperature T, since the Fermi energy E_c the intrinsic semiconductor lies halfway between the forbidden energy gap can be defined as

$$E_g = 2[E_c - E_o] = 2[E_c - E_f]$$
$$n = ce^{Eg/Kt}$$

Sl. No.	Temperature (K)	Resistance of semiconductor (Ω) Heating	Cooling	Mean (Ω)	ln R	$1/T \times 10^{-3}$ K^{-1}
1						
2						
3						
4						
5						
6						
7						

~~Calculation~~

~~Slope = ln R vs. 1/T~~

~~Energy gap = Slope x 2 x K~~

The conductivity $\sigma \propto n$ or relatively $e \propto 1/n$

$$\rho = ce^{-E_g/Kt}$$

$$\log e = \log E_c + E_g/KT \quad [\, R = \frac{\rho l}{A} \,]$$

$$\log R = \log \rho + \log l - \log A$$

Hence E_g can be determined by taking the slope of the graph between ln R and 1/T. R of the sample is found at different temperature using a meterbridge.

So energy gap = (2 x k x slope)eV

Usually C, Si, Ge has similar crystal structure in which each ion is surrounded by few other ions in a tetrahedral array. A band is formed between two neighbouring ions in the lattice by two valence e^- of one atom each. This is called covalent bond.

There is now an energy gap of E_g between the reoccupied band and the conduction band which must be imparted to the valence e^- to enable it to break away from the covalent bonding and they will enter the conduction band where it would be free to migrate along the lines of force applied. So E_g is also a measure of strength of covalent bond.

Eg: Diamond has a covalent bond strength. It is normally possible for an e^- to leave the filled band of diamond at higher temperature and enter conduction band. Thermal energy imparted to e^- by lattice energy vibration is sufficient.

PROCEDURE

1. *The circuit is constructed as shown. A meterbridge p, q, r, s are the arms of the bridge and s is the semi-conductor.*
2. *The variation of resistance with temperature is studied.*
3. *A graph of ln R vs. 1/T is plotted.*

LIGHT SOURCES

Noticeable changes are produced in the appearance of solids when they are heated slowly to incandescence. For eg. Iron or copper when heated to a temperature of 1000 C° appears with a dull red glew. As the temperature is increased the colour changes to orange, then yellow and finally white.

If a metal is slowly being heated and is observed through a prism this is how the colours start to appear at different temperatures.

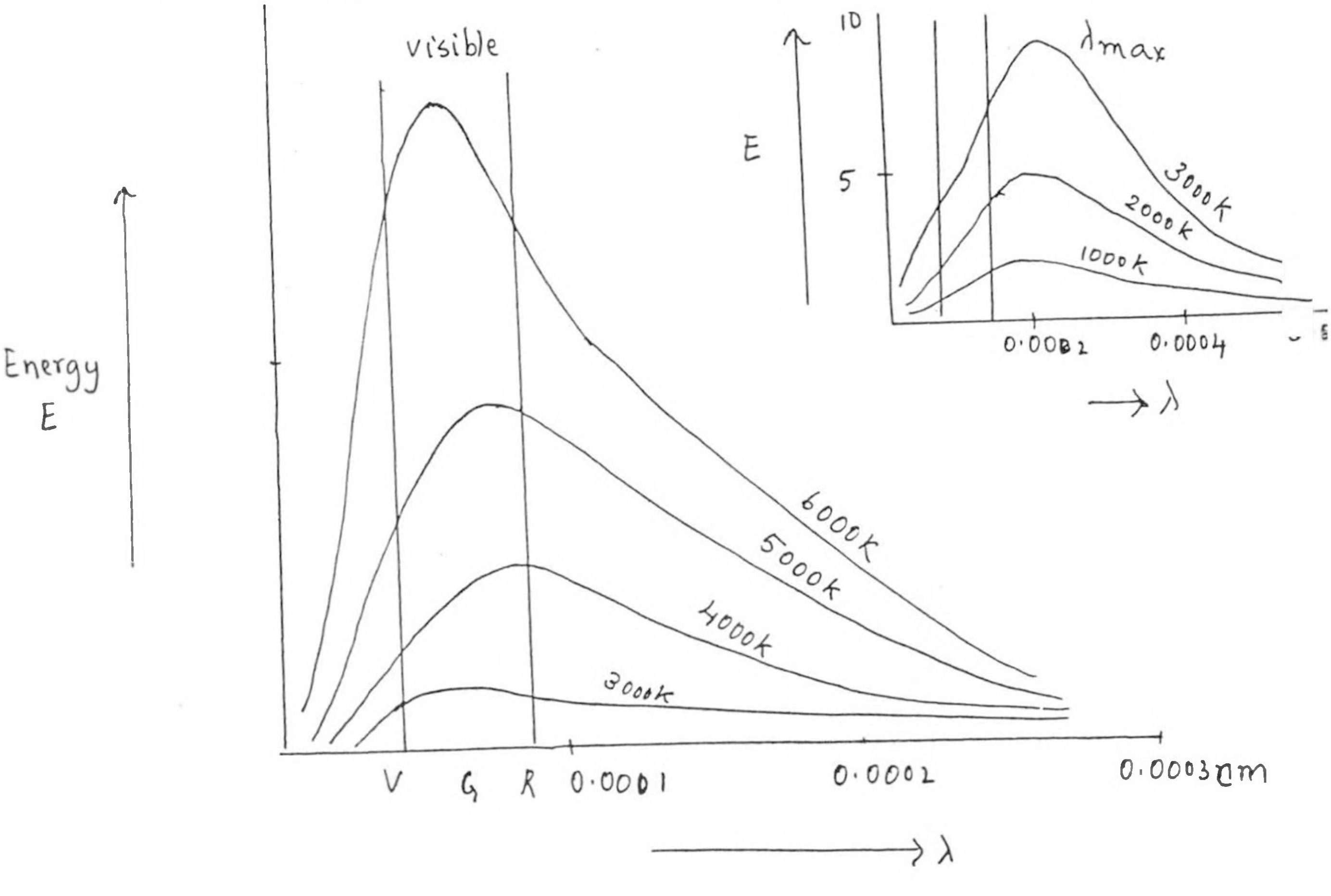
Orange stage 1500°K	- Pure spectrum colours contain red, orange and yellow
Yellow stage 2000°K	- Green is included
White stage 3000°K	- All the colours are included and the spectrum is complete.

So as the temperature increases the spectral colours spread slowly across until the entire band of visible colours from red to violet are seen. Any further rise in temperature results in increase of intensity of each colour without any noticeable change in colour.

The function of the prism is to separate out all the colours from longest red to the shortest violet with the intermediate colours lying in between. The fact that the colour is continuous from red through violet is characteristic of the spectrum of all solids and liquids. **This means that there is a continuous set of different wavelengths present.**

The Spectrum

To show the existence of UV and infrared regions in the spectrum visible light from a carbon arc lamp is made to pass through a quartz lens and prism to be focussed on a nearby screen. To detect the UV region and the IR regions, a flourescent paint photographic plate and a thermopile may be used. The current in the thermopile increases and then drops of and slows as one moves away from the red region of the visible spectrum. A graph of energy from the carbon arc source at 3000°K, for different parts along the screen is as shown below.



Each curve represents the amount of energy given out over the entire spectrum by a solid at different temperatures. On seeing the curves we observe that at low temperatures very little light is emitted in the visible spectrum. At 1000 K only the visible red is seen and even that is very faint. At 2000 K not only does the brightness of red increase, but the other colours, orange, yellow and green appear. At 3000°K, the temperature of a low-current carbon arc or that of tungsten filament light, all of the visible spectrum is emitted but the maximum radiation is in the infrared. At 6000°K, the temperature of the surface of the sun, the maximum energy is radiated in the green of the visible spectrum, with an appreciable amount of UV on the one side and the IR on the other. Thus the visible spectrum, as seen by the human eye, is but a small band out of all the waves emitted by a hot body as the sun.

An interesting fact is that the maximum energy radiated by a hot body shifts to the shorter waves as the temperature rises, i.e. if temperature of the body is doubled, the radiated energy maximum λ_{max}, shifts to 1/2 the wavelength. If the temperature is tripled, the energy maximum shifts to 1/3 the wavelength, etc. This is known as the Wier's displacement law.

$$\lambda_{max} T = C$$

where C is a constant found by experiment to have a value

2.897×10^{-3} m degrees, T is the absolute temperature, and λ_{max} is the wavelength in m at which the maximum energy is radiated.

Classification of spectra

A spectrum may be defined as a smooth and orderly array of wavelengths of light such an array is usually photographed with a prism or diffraction grating spectrograph.

Different sources of light produce different wavelength displays and hence display different spectra. All spectra may be classified into five main classes.

1. Continuous emission spectra
2. Line emission spectra
3. Continuous absorption spectra
4. Line absorption spectra
5. Band spectra

1. Continuous emission spectra: is discussed at the beginning

2. Line emission spectra

Line spectra are given out by vapours and gases in the atomic state. Line spectra is characteristic of the element and is a discontinuous one. The intensities of the lines differ from each other since in a spectroscope (either prism or grating), each transition appears as a line, the spectrum is called a **line spectrum.** Frequently the terms transition and line are used synonymously. The ability to distinguish between two or more wavelengths, differing only slightly from one another, is hence increased by the use of a slit.

The most intense spectral lines are obtained from metallic arcs and sparks. The flame of a carbon arc may be used for demonstration purposes by previously soaking the positive carbon rod in various chemicals. Common salt water gives a bright yellow line characteristic of sodium. Solutions of strontium and calcium chloride will show other strong spectrum lines in the red, green and blue.

While a continuous emission spectrum arises from hot solids, a **line spectrum always arises from a gas at high temperature. It is the gas flame** of the carbon arc that gives rise to the line emission spectrum. At low temperatures line spectrum becomes a band spectrum.

Continuous absorption spectra

They are usually produced by passing the light of a continuous emission spectrum through matter in the solid and/or liquid states. A good absorption spectra can be obtained by allowing white light to pass through coloured glass. When the light is later dispersed by a prism, the missing colours will in general cover a wide band of wavelengths. A red piece of glass for example, will absorb all visible light but the red. A magenta-coloured piece of glass will absorb the whole central part of the visible spectrum.

Line absorption spectra

Line spectra in absorption are produced by sending continuous white light through a gas. Experimentally the gas or vapour is inserted in the path of the light in a long tube. It is later brought to a focus on a screen.

Sodium is chosen as an example because of convenience. The vapour is produced by inserting a small amount of metallic sodium in a partially evacuated glass tube and heating it with a small gas burner. As the metal vapourises, filling the tube with sodium vapour, a dark line will appear in the yellow region of the spectrum. A systematic array of absorption lines occurs with only a few elements, principally with alkali metals like lithium, sodium, potassium, rubidium and caesium. All elements in the gaseous state, however, give rise to a number of absorption lines, usually in the UV region of the spectrum. The absorption of yellow light by normal sodium atoms, for example is a kind of resonance phenomenon. By virtue of their electronic structure atoms have definite and discrete natural frequencies to which they will vibrate in resonance.

When light of one of these frequencies passes by, they respond to the vibration and in so doing absorb the light energy.

The sun's spectrum

The sun's spectrum, consisting of a bright coloured continuous spectrum interspersed by thousands of dark lines was first discovered and studied by Fraunhoffer. Fraunhoffer mapped out several hundred of these lines and labelled eight of the most prominent lines by the first letters of the alphabet. The **strongest** of these lines are called Fraunhoffer lines.

The surface of the sun at a temperature of 6000°K emits all wavelengths, i.e. we get a continuous spectrum. As the light passes through all the cooler gas layers of the solar atmosphere, certain wavelengths are absorbed. Because the absorbing medium is in the gaseous state, the atoms and molecules there do not absorb all wavelengths equally, but rather they absorb principally those wavelengths they would emit if heated to a high temperature. Thus the atoms of one chemical element with their own characteristic frequencies, absorb certain wavelengths, whereas atoms of other elements absorb certain other wavelengths.

Before the sunlight reaches the earth's surface where it can be examined by an observer with a spectrograph, it must again pass through absorbing gases, this time, the earth's atmosphere. Here, too, certain wavelengths are partially absorbed, producing other dark lines.

That the missing lines are due to definite elements can be seen by comparing the sun's spectrum with those of the spectra of known elements. This is how elements which constitute 2/3 of the known ones are identified to be existing on the sun. The reason why not all the elements are found is that some are too rare to produce absorption, whereas for other elements existing within the sun in large enough quantities the temperature is either too high or too low to bring out their lines. Nine prominent Fraunhoffer lines are

A	O_2	$\lambda = 7594$ A
B	O_2	$\lambda = 6870$ A
C	H_2	$\lambda = 6562$ A
D	Na	$\lambda = 5893$ A
E	Fe	$\lambda = 5270$ A
F	H_2	$\lambda = 4861$ A
G	Fe	$\lambda = 4308$ A
H	Ca	$\lambda = 3969$ A
I	Ca	$\lambda = 3935$ A

Band spectra

All of the spectra dealt into so far are known to arise from single free atoms in a heated gas. Molecules of two or more atoms also give rise to spectrum lines grouped together into what are called bands. These bands have the appearance of flutings.

Each fluting in the band spectrum of a diatomic molecule is not a continuous band but a set of regularly spaced lines. The left hand edge of the band is called the band head and the right hand edge the tail. A line near the band head is missing for it is the starting point of the band head, and is called the band origin.

X-ray spectra

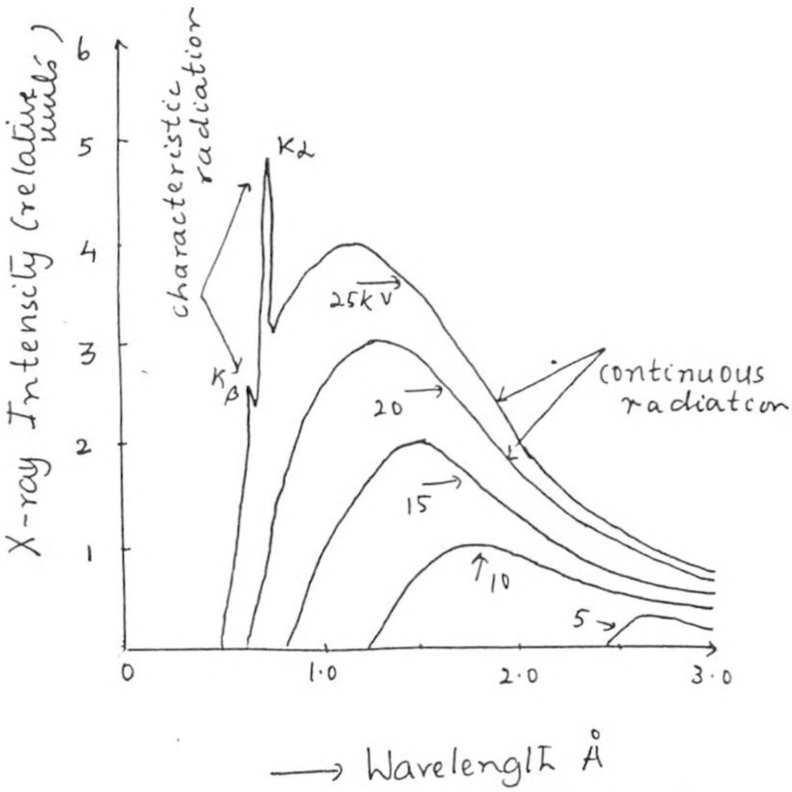
The continuous spectrum

X-rays are produced when any electrically charged particle of sufficient kinetic energy is rapidly decelerated - usually they are electrons. X-rays are produced at the time of impact and radiate in all directions. If e is the associated charge and v the voltage.

$$KE = \frac{1}{2} mv^2 = eV$$

Most of this KE of the electrons striking the target is converted into heat, < 1% being transformed into X-rays.

The rays coming from the target when analysed are found to consist of a mixture of different wavelengths, the variation in intensity depending on the tube voltage. The curves of the type shown below are obtained. The intensity



X-ray spectrum of Mo as a function of applied voltage.

Fig 1.

is **zero** upto a certain wavelength, called **the short wavelength limit** (λ_{SWL}), increases rapidly to a maximum and then decreases, with no sharp limit on the long wavelength side. When the tube voltage is raised the intensity of all the wavelengths increases, both the short-wavelength limit and the position of the maximum shift to shorter wavelengths. Let us consider the smooth curves, those corresponding to the applied voltages of 20 kv or less in the case of a molybdenum target. The radiation represented by such curves is called heterochromatic, continuous, or white radiation, since it is made up, like white light, of rays of many wavelengths.

The continuous spectrum is due to the rapid deceleration of the electrons that hit the target since, as mentioned above, any decelerated charge emits energy. Not every electron is decelerated the same way; however, some are stopped in one impact and give up all their energy at once, while others are deviated this way and that by the atoms of the target, successively, losing fractions of their total kinetic energy until it is all spent. Those electrons which are stopped in one impact will give rise to photons of maximum energy, i.e. to X-rays of minimum wavelength such electrons transfer all their energy in eV into photon energy and we may write

$$eV = h\nu_{max}$$

$$\lambda_{SWL} = \frac{c}{\nu_{max}} = \frac{he}{eV}$$

This equation gives the short-wavelength limit (in A) as a function of the applied voltage V (in practical units). If an electron is not completely stopped in one encounter but undergoes glancing impact which only partially decreases its velocity, there only a fraction of its energy ev is emitted as radiation and the photon has energy less than hv_{max}. In terms of wave motion the corresponding X-ray has a frequency lower than v_{max} and a wavelength longer than λ_{sub}. The totality of these wavelengths, ranging upward from λ_{sm} constitutes the continuous spectrum.

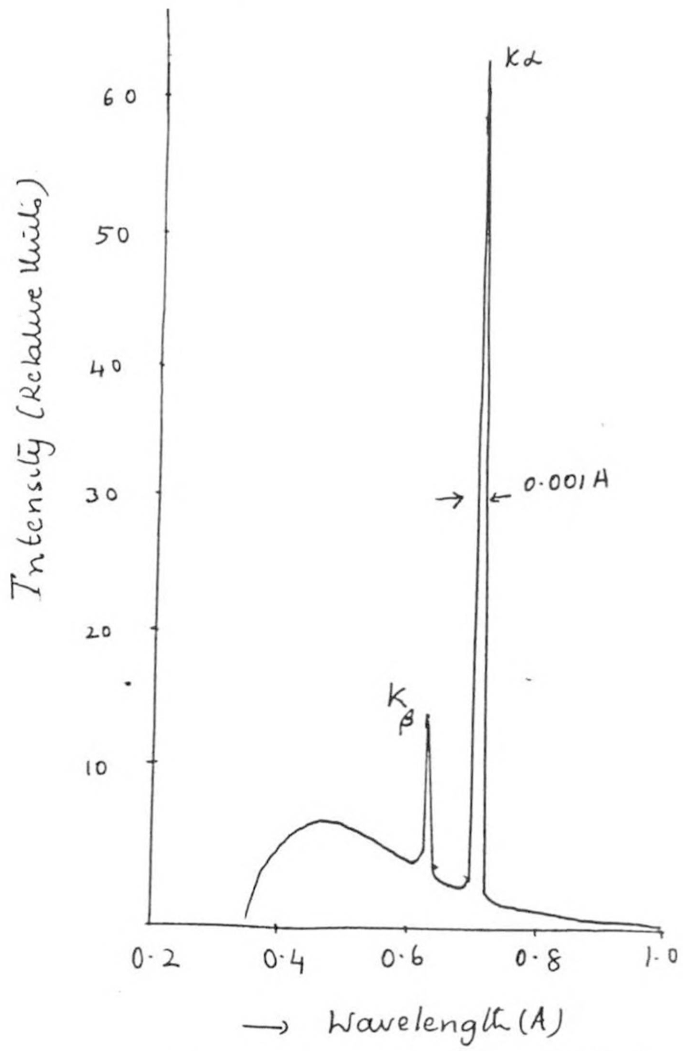
The curves become higher and shift to the left as the applied voltage is increased, since the number of photons produced per second and the average energy per photon are both increasing. The total X-ray energy emitted per second, which is proportional to the area under one of the curves, also depends on the atomic number Z of the target and on the tube current i, the latter being a measure of the number of electrons per second striking the target. This total X-ray intensity is given by

$$I_{\text{Continuous spectrum}} = AiZV^m$$

where m is a constant with a value of 2 and A is a proportionality constant, where large amounts of white radiation are desired, it is necessary to use a heavy metal like tungstun (Z = 74) as a target and as high a voltage as possible. Note: The material of the target affects the intensity but not the wavelength distribution of the continuous spectrum.

The characteristic spectrum

When the voltage on an X-ray tube is raised above a certain critical value, characteristic of the target material, sharp intensity maxima appear at certain wavelengths, superimposed on the continuous spectrum. Since they are so narrow and since their wavelengths are characteristic of the target metal used, they are called characteristic lines. These lines fall into several sets, referred to as K, L, M, etc. in the order of increasing wavelength, all the lines together forming the **characteristic spectrum** of the metal used as the target. For a molybdenum target, the K lines have wavelengths of about



Spectrum of Mo at 35 kV

Fig 2.

0.7 A, the L lines 5A and M lines have still higher wavelengths. Ordinarily only the K lines are useful in X-ray diffraction the longer wavelength lines being too easily absorbed. There are several lines in the K set, but only the three strongest are observed in normal diffraction work. These are K_{α_1} K_{β_2} K_{γ_1}, and for molybdenum their wavelengths are

$$K_{\alpha_1} = 0.70926 \text{ A}$$

$$K_{\beta_2} = 0.71354 \text{ A}$$

$$K_{\gamma_3} = 0.63225 \text{ A}$$

The α_1 and α_2 components have wavelengths so close together that they are not always resolved as separate lines; if resolved, they are called the K_{α} doublet and, if not resolved the K_{α} line. Similarly, the K_{β_1} is usually referred to as the K_{β} line, K_{α_1} is always about twice as strong as K_{α_2}, while the intensity ratio of K_{α_1} to K_{β_1} depends on atomic number.

These characteristic lines are seen in the uppermost curve. Since the critical K **excitation voltage,** i.e. the voltage necessary to excite K characteristic radiation is 20.01 KV for molybdenum, the K lines do not appear in the lower curves. On increasing the voltage above the critical voltage the intensities of the characteristic lines relative to the continuous spectrum increases but the wavelengths do not change. This can be observed in the spectrum of molybdenum given below.

The intensity of any characteristic line, measured above the continuous spectrum, depends both on the tube current i and the amount by which the applied voltage V exceeds the critical excitation voltage for that line. For a K line, the intensity is given by

$$I_{kime} = Bi(V - V_k)^n$$

where

B = Proportionality constant

V_k = K excitation voltage

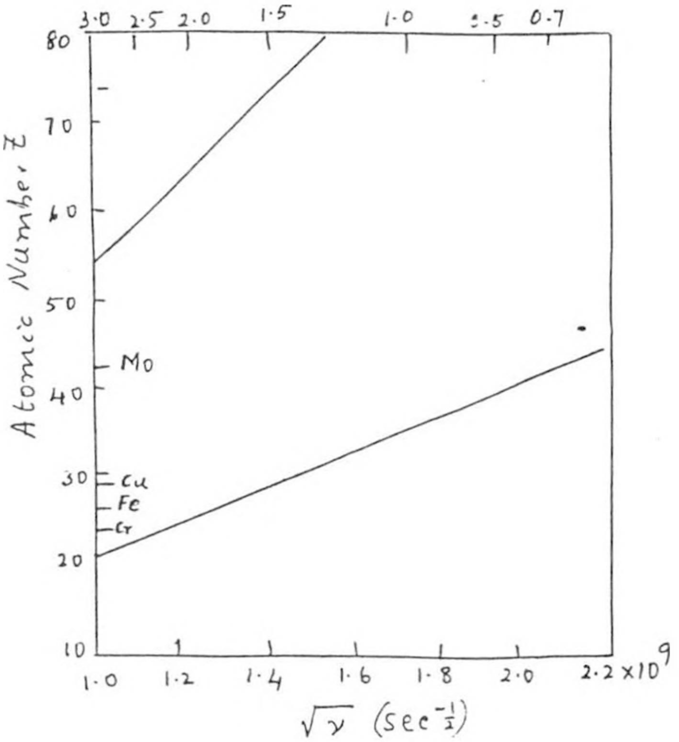
n = Constant with a value about 1.5

The intensity of a characteristic line can be very large, eg. For Cu at 30 KV, K has an intensity 90 times that of the wavelengths immediately adjacent to it in the continuous spectrum. Apart from this the characteristic lines are also very narrow, most of them less than 0.001 A wide measured at half their maximum intensity. The existence of a sharp K line is what makes a great deal of X-ray diffraction possible, since many diffraction experiments require the use of monochromatic or approximately monochromatic radiation.

Characteristic X-ray lines were discovered by Bragg and Moseley. The latter found that the wavelength of any particular line decreased as the atomic number of the emitter increased. In particular, he found a linear relation between the line frequency v and atomic number z (Moseley's law).

$$\sqrt{\nu} = C(Z - \sigma)$$

where C and σ are constants. This relation is plotted in the figure below.



Moseley's relation between √ν and Z for two characteristic lines.

Fig 3

While the continuous spectrum is caused by the rapid deceleration of electrons by the target, the origin of the characteristic spectrum lies in the atoms of the target material itself. To understand this phenomenon, it is enough to consider an atom as consisting of a central nucleus surrounded by electrons lying in various shells in a manner similar to the Bohr atom. If one of the electrons bombarding the target has sufficient KE, it can knock off an electron of the K shell, leaving the atom in an excited, high energy state. One of the outer electrons immediately falls into the vacancy in the K shell, emitting energy in the process, and the atom is once again in its normal energy state. The energy emitted is in the form of radiation of a definite wavelength and is, infact, the characteristic K radiation.

The K-shell vacancy may be filled by an electron from any one of the outer shells, thus giving rise to a series of K lines; K_α, K_β, for example, resulting from the filling of a K shell vacancy by an electron from the L or M shells, respectively. It is possible to fill a K shell vacancy either from L or M shell, so that one atom of the target may be emitting K_α radiation while its neighbour is emitting K_β, however, it is more probable that a K-shell vacancy may be filled by an L electron than by an M electron, and the result is that the K_α line is stronger than the K_β line. It also means that it is impossible to excite one K line without exciting all the others. L characteristic lines originate in a similar way.

We now understand why there should be a critical excitation voltage for characteristic radiation. K line cannot be obtained unless the tube voltage is such that the bombarding electrons have enough energy to knock an electron out of the K shell of a target atom. If W_k is the work required to receive a K electron, then the necessary KE of the electrons is given by

$$\frac{1}{2}mv^2 = W_k$$

Since L electron is farther form the nucleus than the K electron, the L excitation voltage, < K excitation voltage and the K radiation cannot be obtained without the L and M, accompanying it.

BEATS

We have seen that whenever two wave trains of the same frequency travel along the same line in opposite directions, standing waves are formed in accordance with the principle of superposition. The standing wave pattern shows a plot of amplitude of oscillation as a function of distance wherein we could identify the nodes and antinodes. (See Fig.9). Such a phenomenon can be referred to as interference in space.

We can also consider another type of interference, interference in time. This happens when two wavetrains of slightly different frequency travel through the same region. When the two wave trains are sound waves, the resulting phenomenon is called the "beats". When two such sound waves of slightly different frequencies pass through the same region (their amplitudes may or may not be same), a listener will note a regular swelling and fading of the sound. Since the compressions and rarefactions of one sound wave are spread farther apart compared to those in the other wave, at one instant two compressions may arrive simultaneously at the ear of the listener and the sound heard is louder. At a later time, the compression of one wave and the rarefaction of another wave may arrive together wherein the sound heard is of feeble intensity.

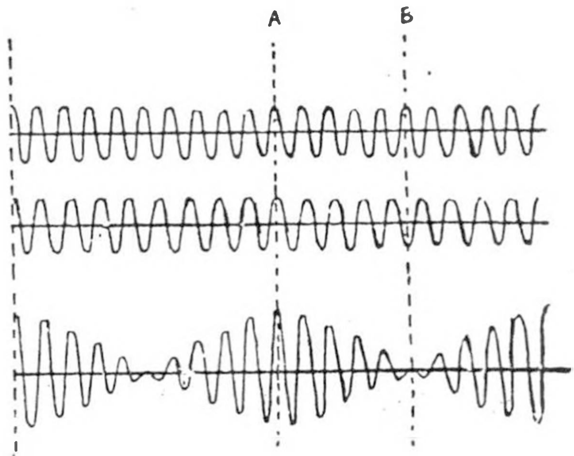


Fig. 11

At any point the variation of pressure in the two waves may be written as

$p_1 = P \sin 2\pi f_1 t$ and

$p_2 = P \sin 2\pi f_2 t$

For simplicity, we assume the pressure amplitude P to be same. When the two waves are superposed, the resultant pressure is given by

$$p = p_1 + p_2 = P(\sin 2\pi f_1 t + \sin 2\pi f_2 t)$$

Using the trigonometric identity,

$$Sin\ A + Sin\ B = 2\ Cos\ \frac{a - b}{2}\ Sin\ \frac{a + b}{2},$$ we get

$$p = 2P \cos\left(2\pi\left(\frac{f_1 - f_2}{2}\right)t\right) \sin\left(2\pi\left(\frac{f_1 + f_2}{2}\right)t\right) \qquad (16)$$

The above expression may be interpreted as a vibration of frequency $\frac{f_1 + f_2}{2}$, the average of f_1 and f_2 whose amplitude also varies with time in the form $2P \cos 2\pi\left(\frac{f_1 - f_2}{2}\right)t$, i.e. the amplitude of vibration varies with a frequency $\frac{f_1 - f_2}{2}$. The amplitude is a maximum resulting in loudest sound whenever the cosine term has a value either +1 or -1. Since these values appear twice in a cycle, the frequency of beats is twice, $\frac{f_1 - f_2}{2} = f_1 - f_2$. Hence the number of beats per second equals the *difference of frequencies of the component waves.* When the difference of frequency of the two waves is small, the variation in intensity is readily observed by listening to it. As the difference increases beyond 8 or 10 per second, it becomes increasingly difficult to distinguish them separately.

To consider a mathematical analysis, it is easier to work with exponentials than with sines and cosines. We know that $P_1 \cos \omega_1 t$ is just the real part of $P_1 \exp[j\omega_1 t]$; similarly $P_2 \cos \omega_2 t$ is the real part of $P_2 \exp(j\omega_2 t)$. The resultant is obtained by adding these two -

$$P_1 \exp(j\omega_1 t) + P_2 \exp(j\omega_2 t)$$

This can be shown to be

$$e^{\frac{1}{2}j(\omega_1 + \omega_2)t}\left[P_1 e^{\frac{1}{2}j(\omega_1 - \omega_2)t} + P_2 e^{-\frac{1}{2}j(\omega_1 - \omega_2)t}\right] \qquad (17$$

To find the intensity of the wave we can take the absolute square of either side. We get $I = P_1^2 + P_2^2 + 2P_1 P_2 \cos(\omega_1 - \omega_2)t$. Thus the intensity swells and falls between $(P_1 + P_2)^2$ and $(P_1 - P_2)^2$ at a frequency $\omega_1 - \omega_2$. The minimum intensity goes to zero only when $P_1 = P_2$.

We may also represent the phenomenon of beats by using a vector diagram. Fig.(11) shows the addition of two vectors of length A_1 and A_2 where A_1 rotates with a frequency ω_1 and A_2 rotates with a frequency ω_2. If ω_1 and ω_2 are exactly equal as in fig.(12), their resultant is of fixed length as it keeps revolving and we get a definite fixed intensity.

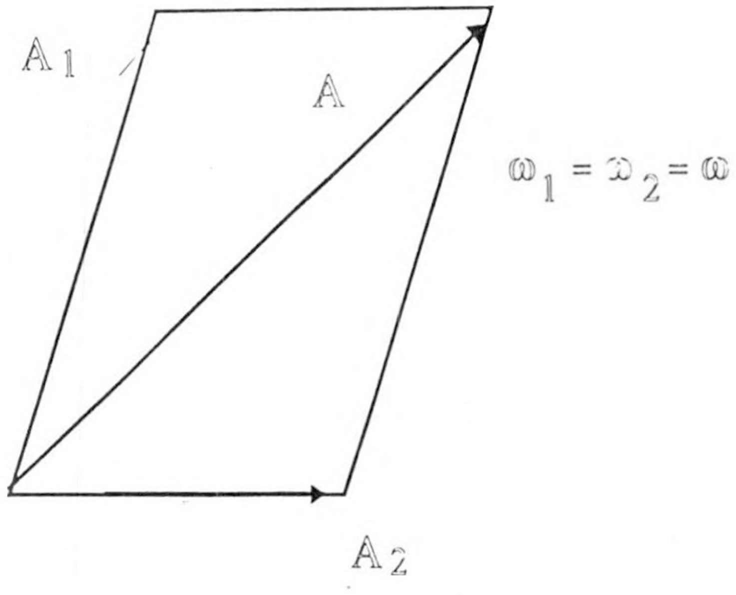


Fig.12

But if the frequencies are slightly different, the two vectors go around at different speeds. Let us imagine A_1 being fixed and A_2 going around relative to A_1. As A_2 slowly turns away from A_1, the amplitude (or resultant) varies from a maximum to a minimum. Thus the intensity pulsates between a maximum and a minimum.

DOPPLER EFFECT

Doppler effect is applicable to waves in general. In the case of sound waves, when the listener is in motion toward a stationary source of sound, the pitch or frequency of the sound heard is higher than when he is at rest. On the other hand, if the listener is moving away from the stationary source of sound, he hears a lower pitch than when he is at rest. Similar results can also be obtained if the source of sound moves toward/away from a stationary listener. For example, the pitch of the whistle of the approaching train is higher compared to that of a receding train.

An expression for the change in frequency can be obtained by using the basic picture of wave motion through a medium. Consider the case where the source and/or the listener move through the medium along the line joining them. We assume our reference frame to be at rest in the medium. The source of sound S (See Fig. 13) is at rest in this frame and the observer (shown by the ear) is moving towards the source at a speed υ_0. The wavefronts due to the sound waves emitted by the source is travelling through the medium.

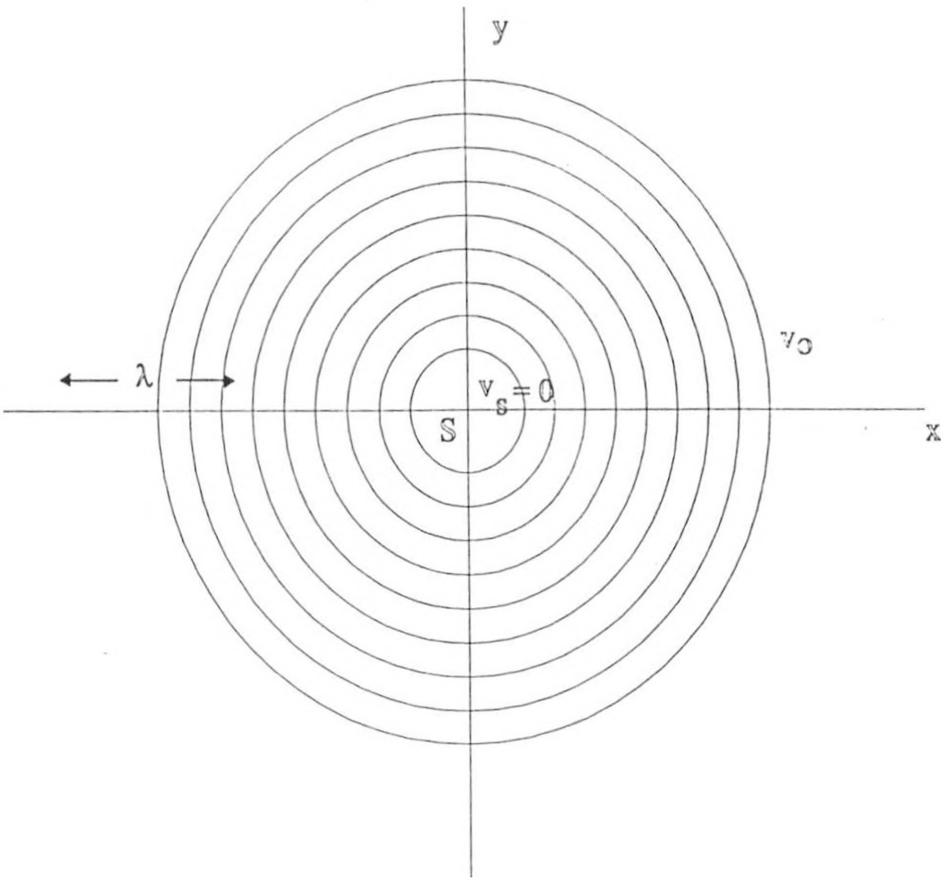


Fig.13 Source at rest, Observer moving toward Source with speed υ_0

The circles represent these wave fronts (we assume a point source so that the wavefronts are spherical in shape) and they are shown a distance λ apart, where λ is the wavelength of the sound. If the observer were at rest in the medium, he would receive in a time t, $\upsilon t/\lambda$ no. of waves where υ is the speed of the sound in the medium. But if he is moving toward the source, he should intercept more number of waves depending on his speed. Since υ_0 is the speed of the observer, he sees an *additional* $\upsilon_0 t/\lambda$ number of waves in the same time t. The frequency that he hears is the number of waves received per unit time i.e.

$$\gamma' = \frac{\frac{\nu t}{\lambda} + \frac{\nu_o t}{\lambda}}{t} = \frac{\nu + \nu_o}{\lambda} = \frac{\nu + \nu_o}{\left(\frac{\nu}{\gamma}\right)}$$

or, $$\gamma' = \gamma \frac{\nu + \nu_o}{\nu} = \gamma \left(1 + \frac{\nu_o}{\nu} \right) \qquad (18)$$

Thus we can say that the frequency he hears now is equal to the ordinary frequency γ of the source plus the increase $\gamma \frac{\nu_o}{\nu}$ which arises due to his motion towards the source of sound. By symmetry we can expect that the observer intercepts in time t a lesser number of $\upsilon_0 t/\gamma$ when he moves away from the source of sound. This results in a decrease in frequency corresponding to the number of waves (per unit time) that do not reach him due to his receding motion. Then,

$$\gamma' = \gamma \frac{\nu - \nu_o}{\nu} = \gamma \left(1 - \frac{\nu_o}{\nu} \right) \qquad (19)$$

Hence, combining these two cases the frequency heard when the observer is in motion with respect to the source at rest in the medium is given by.

$$\gamma' = \gamma \left(\frac{\nu \pm \nu_o}{\nu} \right) \qquad (20)$$

The plus sign is when the observer is moving toward the source and the minus sign when he is moving away from it. From the results, we may see that the reason for change in frequency heard is due to the lesser or more number of waves per second intercepted by the listener. Since frequency heard corresponds to the number of waves intercepted per second, a moving observer intercepts more number of waves when he moves toward a stationary source and less when he moves away from it.

Case (ii) Source is in motion toward a stationary observer

From the Fig.14, we can see that when the source is moving toward a stationary observer, the source follows the waves which are moving toward the observer. Therefore, the crests come closer and closer resulting in a shortening of the wavelength. Let γ be the frequency of the source, and υ_s the speed of the source (which is in motion toward the observer). During the time period T the source travels a distance $\upsilon_s T = \upsilon_s/\gamma$. Hence the listener comes across waves whose wavelength is not υ/γ but

$\frac{v}{\gamma} - \frac{v_s}{\gamma}$ i.e., the wavelength seen $\lambda' = \frac{v}{\gamma} - \frac{v_s}{\gamma}$ Since the wavelength has decreased the frequency of the sound heard by the observer is increased. The new frequency

$$\gamma' = \frac{v}{\lambda'} = \frac{v}{(v - v_s)/\gamma} = \gamma\left(\frac{v}{v - v_s}\right) \tag{21}$$

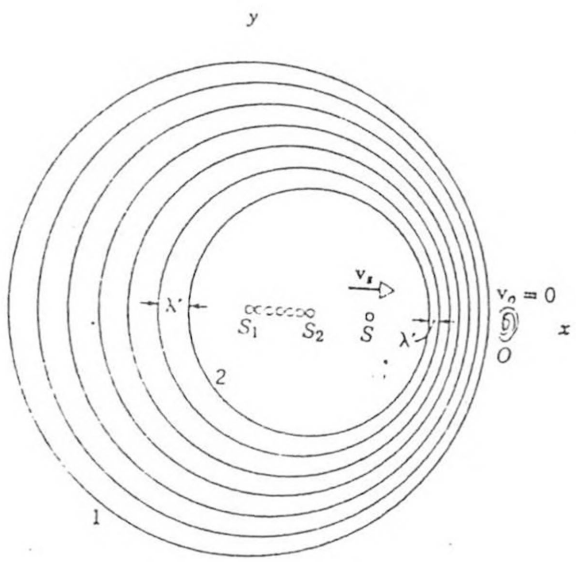


Fig.14 Observer at rest. Source moving toward observer with speed υ_s

A similar argument can be applied when the source moves away from the stationary listener. In this case, there is an increase in wavelength and a consequent decrease in the frequency heard by the observer. The frequency heard γ' is given by

$$\gamma' = \frac{v}{\lambda'} = \frac{v}{(v + v_s)/\gamma} = \gamma\,\frac{v}{v + v_s} \tag{22}$$

Combining these two, the general expression for the frequency heard when the observer is at rest with respect to the medium and the source is moving with speed υ_s through the medium is given by

$$\gamma' = \gamma \frac{v}{v \mp v_s} \qquad (23)$$

The minus sign is applicable when the source is moving toward the listener and the plus sign when it is moving away from him. The reason for the change in frequency is due to the fact that the motion of the source through the medium increases or decreases the wavelength of the waves transmitted through the medium.

If both the source and the observer move through the transmitting medium, one can show that the observer hears a frequency

$$\gamma' = \gamma \left(\frac{v \pm v_o}{v \mp v_s} \right) \qquad (24)$$

where γ is the frequency of the sound emitted by the source. The upper sign corresponds to the case where the source and observer move *toward* each other and the lower sign when they move away from each other. In both cases, the motions are assumed to be along the line joining the source and the observer.

A demonstration of Doppler effect may be done as follows. Arrange a vibrating tuning fork on its resonating box and mount the same on a dynamic cart. Moving the cart rapidly toward a wall (with the tuning fork resonating on it) , one could hear two notes of different frequencies. One is the note heard directly from the receding tuning fork and is lowered in pitch due to its motion away from the listener. The other note is due to the waves reflected from the wall and this note is raised in its pitch. The super-position of these two produces beats.

Doppler Effect for light

In the case of sound waves, we got the following results for the Doppler frequency.

$$\gamma' = \gamma \frac{v}{v + v_s}$$

where υ_s represents the speed with which the source of sound moves away from the listener; γ is the frequency heard when the source is at rest and γ' is the frequency heard when the source is in motion, υ is the speed of sound in the medium.

Let us put $\upsilon_s = u$. After rearranging we may write $\gamma' = \gamma \dfrac{1}{1 + \dfrac{u}{\nu}}$. If the source is at rest and the observer is moving away from the source at speed u, we may write,

$$\gamma' = \gamma \left(1 - \frac{u}{\nu} \right)$$

where υ represents the speed of sound. We have also seen that even if the relative speeds u of the source and observer are the same, the frequencies predicted by these two relations are different. This is because, a source of sound moving through a medium in which the observer is at rest is physically different from an observer moving through the medium in which the source is at rest.

Can we apply these two equations to light by replacing υ by c, the speed of light? Since light does not depend on a medium of transmission, "a source receding from observer" and "an observer receding from source" are physically identical situations. Hence in both cases, the Doppler frequency must be the same. From theory of relativity, one can show that the Doppler frequency is given by

$$\gamma' = \gamma \frac{1 - \dfrac{u}{c}}{\sqrt{1 - \left(\dfrac{u}{c}\right)^2}} \qquad (25)$$

where u represents the relative speed between source and observer when they are *separating* from each other.

By replacing u by -u we get the relation when they approach each other. These three relations are not so different when the ratio u/c is small. Thus we may say eqn. (25) is more general.

Applications in Astronomy

Doppler effect for light finds many applications in astronomy. It is used to determine the speed with which luminous celestial bodies are moving toward us or receding from us. All galaxies for which such measurements have been done appear to be receding from us, the recession velocity being greater for the more distant galaxies. These observations form the basis of the theory of expanding universe.