5.2 Other experimental problems and demonstrations

In the earlier section of this chapter, we have described a specimen experimental problem and its demonstration in detail. We feel that it is not necessary and even possible to give all such details for the remaining nine experimental problems and demonstrations developed by us. We have given the students' handout for all the nine experimental problems in **Appendix A** and the instructors' handout for all the nine demonstrations in **Appendix B** at the end of this thesis. Here, we describe briefly for each experimental problem, its brief description, the necessary experimental arrangement and the salient features. Along with each experimental problem, the objective and the brief description of each of the accompanying demonstration are also given.

5.2.1 Experimental Problem No. 2

A) Brief description

It is observed that, in most of the experimental situations, while determining the spring constant for a spring (with a spring mass system), we neglect the effect of the mass of the spring on the equilibrium extension of the spring or on the time period of oscillations for a given mass attached to the lower end of the spring. It is found that in case of soft massive springs, the mass of the spring cannot be neglected. These types of springs have extension under their own weight and therefore need a correction for this extension. Similarly, these springs can oscillate without any attached mass, which implies that the standard formula for the time period of oscillations of a spring mass system needs modifications. We have theoretically worked out the modification and corrected the formula for the determination of equilibrium extension and also the time period of oscillations. Interestingly, one finds that the mass correction factor in these two cases is not the same.

In part A and B of this experimental problem, students are supposed to determine the spring constant and the mass correction factor for the given soft massive spring and verify the modified formulas in both the static (i.e. extension) and dynamic (i.e. oscillations) cases.

A soft massive spring clamped at both the ends can be assumed to be a uniformly distributed mass system. It has its own natural frequencies of oscillations (corresponding to different normal modes) like a hollow pipe closed at both the ends. Using the method of resonance one can excite different normal modes of oscillations of the spring. In part

C, of the experimental problem, students are supposed to use a variable frequency mechanical vibrator assembly to force oscillations on the spring. They use this to excite different normal modes of oscillations of the spring and study the longitudinal stationary waves on the spring. Students also measure the frequencies of oscillations corresponding to different normal modes. From these, they determine the fundamental frequency of oscillation with both the ends fixed and compare it with the frequency of oscillations with one end fixed and the other end free as determined in part B of the experimental problem.

B) Experimental arrangement

The complete experimental arrangement for this experimental problem is as shown in Fig. 5.2.1, which is shown below. For part A and B, students are given identical soft massive springs, a retort stand with the clamp and a bosshead, weights along with their hooks, measuring tape / scale and a hand held digital stop clock. The experimental arrangement for part A is very simple, in which a spring may be clamped

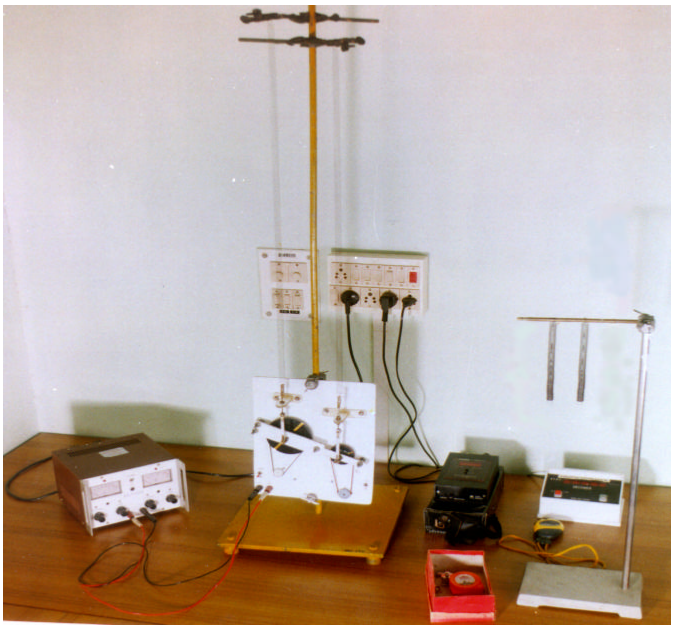

Fig. 5.2.1 The complete experimental arrangement

to the stand at its upper end. Different weights can be attached to the lower end of the spring and the extended length of the spring may be measured for different attached weights. In part B, the spring mass system may be set into oscillations and the time period of oscillations of the spring mass system may be measured for different attached weights. These measurements allow the students to determine experimentally the spring constant and also the mass correction factor in both the cases.

For part C, students are provided with a long and heavy retort stand with clamps, a variable frequency mechanical vibrator assembly, a digital tachometer, a D.C. regulated power supply and two connecting cords. In this case two identical soft massive springs are clamped at the upper end on the long retort stand. The variable frequency mechanical vibrator is fixed near the base of the retort stand. The lower ends of the springs are fixed to the vibrating strip of the vibrator. The vibrator assembly consists of two independent vibrators, identical in principle, but their vibrating frequencies are different. For vibrator A, the maximum frequency is 20 Hz and the vibrator B can go up to 80Hz. A D.C. regulated variable power supply (0 –30 V, 1A) is used to supply the necessary power to the vibrator assembly. The frequency of vibrations may be controlled and tuned by changing the voltage applied and the current. A digital non-contact type tachometer is provided to measure the frequency of vibrations i.e. forced frequency.

Students are supposed to excite different normal modes of oscillations by tuning the frequency of the vibrator. These resonant frequencies are to be measured and from this data, by plotting a graph, the value of the fundamental frequency is to be determined.

C) Salient features

In this experimental problem, the development of laboratory skills involved in adjustment, measurement, use of apparatus, judgment and control are emphasized along with the procedural understanding and different concepts of evidence. This problem is designed basically to verify and support experimentally, a modified version for a well-known formula. It also is a unique experimental situation, which demonstrates the stationary longitudinal waves on a spring system, which otherwise are always observed indirectly. This problem is designed to develop in students, concepts of evidence required for design, measurement and data handling. It also helps students foster different cognitive abilities like interpreting and inferring.

In this experimental problem, students are given instructions on the use of a digital hand held tachometer, variable frequency mechanical vibrator assembly, D.C. regulated power supply and the digital stop clock. They are also given some simple procedural instructions. In the students' handout, five questions are asked, which are designed around the concepts of evidence related to design and data handling, and conceptual understanding. The problem involves inquiry, skills and investigation type of practical work.

We describe below the learning objectives of the questions asked in the handout. Q. 1 and 2. are intended to develop an understanding about selection of variables and choice of scale while plotting a graph. It also demands the ability to explain the behavior or the interdependence of the parameters plotted. It also helps in using and interpreting the data presented in the form of a graph to derive the meaningful results. Q.3 is intended to develop an understanding about the techniques and methods of measurements and their advantages. Q.4 helps students to develop the procedural understanding especially the concepts of evidence related to the design of an experiment. Q.5 is intended to develop an ability to synthesize and apply acquired conceptual understanding to a new situation in order to explain the theoretical basis of observed behavior.

We feel that it is not necessary to give here all the details about different learning outcomes (as given for experimental problem No. 1) for this experimental problem. We found that the substantive concepts involved in this experimental problem, are elementary concepts in mechanics, especially in simple harmonic oscillation, waves and static and dynamic behavior of a spring mass system. The laboratory skills involved are of the following types: 1) Handling or manipulation 2) Alignment or judgment 3) Use of instruments 4) Measurements and control 5) Drawing graphs and tables.

Thus this experimental problem is designed to develop in students laboratory skills, procedural understanding and concepts of evidence associated with design, measurement and data handling.

5.2.2 Demonstration No. 2

A) The objective

The following demonstration serves as a prelude to Experimental Problem No. 2. For the delivery of this demonstration we follow the same format as is used for demonstration No.1. The demonstration is delivered in an interactive manner, in which the instructor asks questions to the students and gets them answered from the students. He may provide some hints if found necessary. This demonstration is designed around illustration and observation type of practical work.

The demonstration illustrates and explains the concept of stationary waves in the transverse mode and dependence of the number of harmonics (loops) on the tension in the string and the length of the string.

B) Brief description

In the experimental set up for this demonstration, a long metal rod is attached to a fixed frequency vibrator, which vibrates with mains frequency i.e. 50 Hz. Five elastic strings are tied to this vibrating metal rod and the other ends of the strings are clamped on the aluminum stand as shown in Fig.5.2.2 The strings can be stretched and the tension in the string may be adjusted using the clamping screws.

In this experimental set up, we found that an elastic string gives a fairly steady and visible stationary wave pattern. It is observed that with the elastic strings we can simultaneously observe on different strings, stationary waves corresponding to fundamental to fifth harmonic. Hence, in spite of the fact that the mass per unit length of the elastic strings changes with its stretching, we have used the elastic strings for this demonstration. In this demonstration by adjusting the amount of stretching of the string

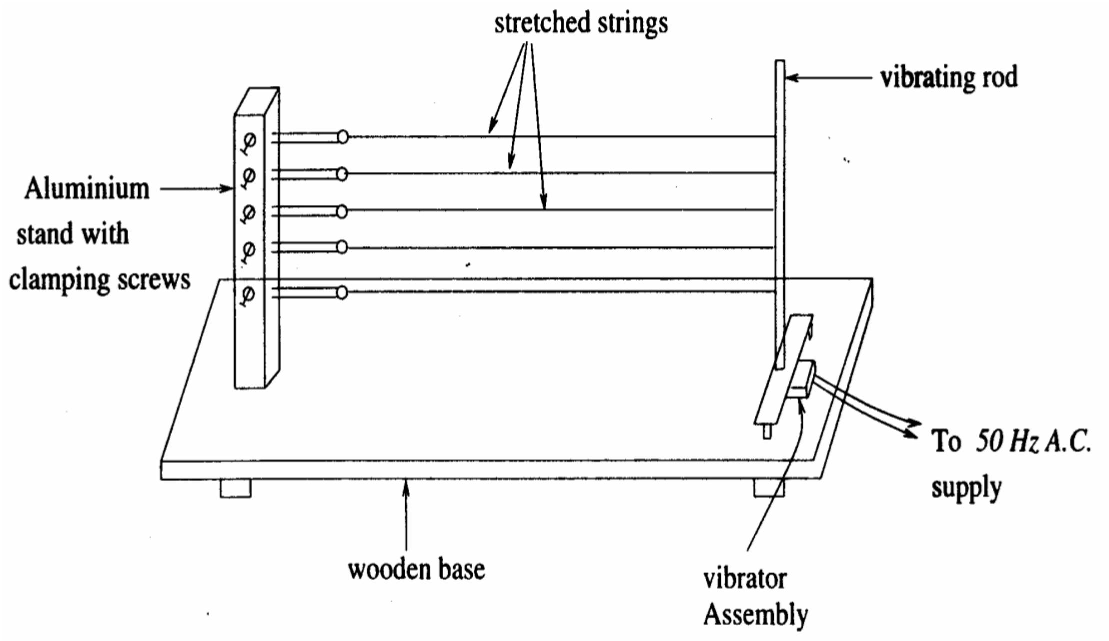

Fig. 5.2.2 The demonstration set-up

one may excite different normal modes of vibrations of the string. The instructor is supposed to demonstrate the stationary wave pattern on the string. For this demonstration six questions are designed which illustrates concepts like stationary waves, resonance, node and antinode. The dependence of number of harmonics on the tension in the string and the length of the string is also explained.

More information about the questions and the explanation along with the other details of the demonstration are included in the instructor's handout given in the Appendix B.

5.2.3 Experimental Problem No. 3

A) Brief description

As we know the operational amplifier (Op-Amp) is a very useful device for constructing different analog or digital circuits. Its unique characteristics (i.e. high input impedance, low output impedance and high open loop gain) make it even more suitable in constructing circuits to be used for performing different mathematical operations. In this experimental problem, a circuit of a tunable sharp filter is given to the students. The circuit is deigned using three Op-Amps, two of which are used as integrators and the third one as a unity gain inverter. This circuit filters out only those sinusoidal waves, which match with its tuned frequency. The tuned frequency of the filter may be changed by altering the values of resistors and capacitors.

In Part A of this problem, students are supposed to study a Op-Amp based tunable filter circuit. In this they observe the output waveforms and amplitudes for different input waveforms (i.e. sine, square, triangular, ramp, etc.) of different frequencies and amplitudes near and below the theoretically calculated tuned frequency of the filter. In Part B, the students are supposed to Fourier analyze a square waveform using sharp Op-Amp filter circuit tuned at a fixed frequency. In this Part, the tuned frequency of the filter is fixed whereas the input frequency is changed to infer about the frequency ratios and the amplitude ratios for the different sinusoidal components. That is, the students have to change the input frequency of the square wave keeping the input voltage (i.e. amplitude) constant and when any harmonic of this frequency matches with the tuned frequency of the filter, they get voltage maxima at the output. This method of Fourier analysis is permitted in our case since we note that for square waves the amplitudes a_1, a_3, a_5, $a_7, \ldots\ldots\ldots$for different harmonics depends only on the value of V_o i.e. the maximum amplitude of the wave to be analyzed.

In Part C of the problem, the students are supposed to design an appropriate method to Fourier analyze a triangular waveform and determine the amplitudes and frequencies of different sine and cosine (if any) components present in the waveform.

B) Experimental arrangement

The experimental arrangement for this problem is as shown below in Fig. 5.2.3. Three operational amplifier (IC 741) circuit boards are provided with different connecting sockets. These boards can be used to connect the Op-Amps in the desired configuration. On these circuit boards, fixed value resistors and capacitors are provided, which may be connected in the feedback or the input circuit. A Γ15V d.c. regulated power supply is available to provide the necessary power to the Op-Amps. A function generator is provided which may be used to apply different waveforms at the input of the

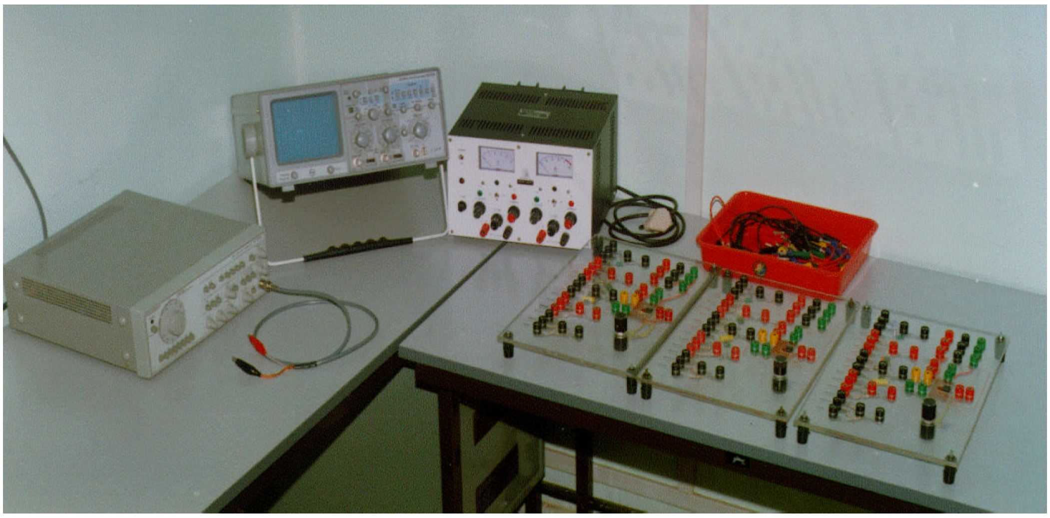

Fig. 5.2.3 The complete experimental arrangement

filter. A dual trace cathode ray oscilloscope (CRO) with auto measurement facility is provided to observe the waveforms and carry out the desired measurements. Two digital multimeters are provided which can be used for the measurement of frequency or the amplitude (i.e. the voltage) of the waveforms. A set of connecting cords and B.N.C. connectors are made available for the connections to be made on the circuit boards.

C) Salient features

In this experimental problem the development of concepts of evidence associated with design and procedural understanding is emphasized along with the skill involved in the use of instruments. Students are supposed to design an experimental procedure to Fourier analyze the waveform and perform the required measurements to determine the frequencies and amplitudes of the Fourier components present in the given wave form.

This experimental problem is designed, to introduce a technique of Fourier analysis to the students and also to develop the problem solving ability in experimental physics. This problem is mainly based on the problem solving or investigation type of practical work, but it also involves skill and exploratory type of practical work. In Part A of the problem, students are supposed to explore and study the input-output behavior of a filter circuit tuned at a fixed frequency. This also involves skills needed to use different electronic instruments to perform the desired measurements.

In this problem, the students are given instructions on the use of Op-Amp circuit boards, dual trace CRO, d.c. regulated power supply, function (signal) generator and digital multimeters. They are not given any procedural instructions; instead, they are supposed to design their own method of Fourier analysis. In this problem three questions are asked which are mainly based on concepts of evidence related to design and procedural understanding.

Thus this experimental problem is designed to develop problem solving ability, concepts of evidence associated with design and procedural understanding along with the skill involved in the of use of instruments. It also introduces a technique of Fourier analysis using a simple circuit.

5.2.4 Demonstration No. 3

A) The objective

This demonstration serves as a prelude to Experimental Problem No. 3. This demonstration is delivered to students in an interactive manner. It is designed around illustration and observation type of practical work.

In the experimental problem, students are supposed to Fourier analyze a square and a triangular wave using a sharp filter circuit constructed using operational amplifiers (Op-Amps). We found that for the students it is difficult to understand the use and working of the filter circuit, which uses three Op-Amps, two of which are used as integrators and the third one as unity gain inverter. Hence we have designed this demonstration, which aims at introducing to the students the use of the new device, i.e. Op-Amp and familiarizing them with the two circuits made of Op-Amps, namely, a unity gain inverter and an integrator.

This demonstration explains the input output characteristics and the principle of working of these two circuits. It also explains the concept of gain, (i.e. voltage gain) inversion, integration, amplification and attenuation.

B) Brief description

The experimental set-up for this demonstration consists of one Op-Amp (IC 741) circuit board, one dual trace CRO, one d.c. regulated power supply, one signal generator, connecting cords and B.N.C. connectors. The Op-Amp circuit board consists of a 741 IC Op-Amp, with the connections taken out as terminal and a set of fixed value resistors and capacitors. The Op-Amp can be connected in different configurations using these resistors and capacitors provided on the board. A dual trace CRO is used to observe the input or output waveforms and to perform voltage and frequency measurements. A d.c. regulated power supply is used to provide the necessary power to the Op-Amp IC. A signal generator is used to take out different waveforms to be applied as the inputs to different circuits.

In part A, B and C of the demonstration the input-output relations and the working of an inverting amplifier is studied. In this study, the students are experimentally shown and explained, the gain dependence on the value of feedback resistor R_f for a fixed value of input resistance R_{in}. Then the working of a unity gain inverter is explained to students wherein $R_f = R_{in}$. Students are also given information on an inverting attenuator for a fixed frequency.

Then in parts D, E and F of the demonstration a simple ideal Op-Amp circuit for an integrator is explained to the students. Students are given information on how it works as an integrator. The input and output relationship is explained and actually demonstrated on CRO for different input signals i.e. d.c., square, sine and triangular. It also explains how the same circuit acts as an active low pass filter.

5.2.5 Experimental Problem No. 4

A) Brief description

In this experimental problem, students are supposed to study two different configurations of a magnetic circuit. Through this problem, we introduce and explain the basic concepts like magnetic flux, electromotive force, magneto motive force, magnetic circuit and reflected impedance. We know that in case of a transformer core, the magnetic flux generated by the current in the coils is confined to the core due to its high magnetic permeability and absence of air gaps. The transformer core used in this experimental problem presents an interesting example of a simple magnetic circuit. In Part A of the problem, a configuration of a two loop magnetic circuit is considered in which two coils are wound on the central leg on an ordinary laminated iron core. The two coils i.e. primary and secondary are wound with 1:1 turns ratio and 300 turns each of 23 *SWG* copper wire. The cross sectional area of the central leg is twice that of the extreme legs. Students are supposed to pass a current through the primary and perform the necessary measurements of currents and voltages with different load resistance in the secondary circuit. They are supposed to explain the variation of current and voltage in the primary due to different loading at the secondary and hence explain the concept of reflected impedance.

In Part B of the problem, a more involved and interesting configuration of a magnetic circuit is considered, in which three coils are wound on three legs of an ordinary laminated iron core. In this case also, the cross sectional area of the central leg is twice that of the extreme legs. Three coils i.e. a primary, left secondary and right secondary are wound on each of the three legs with the turns ratio 1:1:1 and 80 turns of 15 *SWG* copper wire. Students are supposed to establish a current in the primary coil using an external source and the analysis of currents in the primary and both the secondary coils is to be done for different loads connected in both the secondary circuits. Students are also supposed to verify and explain theoretically the expected current and voltage relationships with different loading at the secondary coils.

B) Experimental arrangement

As described earlier, in Part A of the problem a simple configuration of a magnetic circuit is considered which is designed around a three legged transformer, in which two coils of copper wire each of 300 turns are wound on the central leg of the laminated iron core. The cross sectional area of the central leg is twice that of the extreme legs. One of the coils may serve as a primary and the other secondary. This transformer is fixed on a wooden board and the connecting terminals for the coils are provided on the board. Three high watt fixed value resistors are provided on the board, which may be used for the measurements or to limit the current. Also a 6 *Volt*, 15 *Watt* bulb is provided with its connecting holder. An 18 - 0 - 18 *Volt*, 2 *Amp* step down

Fig. 5.2.5 The complete experimental set-up

transformer is used to supply the necessary current in the circuit. Digital multimeters are provided to measure the voltages and currents. The complete experimental arrangement for this experimental problem is, as shown in Fig. 5.2.5.

For Part B of the experimental problem the magnetic circuit is designed around a three-legged transformer core. As described earlier, the core is a normal laminated iron core wound with 80 turns of 15 *SWG* copper wire on each leg. The cross sectional area of the central leg on which the primary coil is wound, is twice that of either of the side legs on which the secondary coils are wound. The connecting terminals are provided for each coil. A 6 *Volt*, 2 *Amp*, supply drawn from a step down transformer is provided to establish the necessary current in the primary coil. A 6 *Volt*, 15 *Watt* bulb is provided, which may be used as a load for the demonstration. A resistor ladder is provided, which consists of a set of resistors mounted on a wooden board with their connecting sockets. The resistors may be connected in series or in parallel as per the requirement. Digital multimeters are provided to measure currents and voltages. Two rheostats with three stages of resistance 10 *W*, 25 *W* and 50 *W* with 5 *Amp* current capacity are provided which may be used as a variable load in the secondary circuits. Also provided are the connecting cords.

C) Salient features

This experimental problem is designed to develop conceptual understanding in the field of dynamic electricity and magnetism; particularly, concepts like magnetic flux, electro-motive force, magneto-motive force, magnetic circuits and reflected impedance. It builds students' understanding about the principle and the working of a transformer on the basis of simple concepts and laws.

In this problem, the emphasis is on the development of conceptual understanding rather than on procedural understanding and hence concepts of evidence. Also, the problem involves relatively simple laboratory skills with respect to use of instruments. It is designed basically to verify and support experimentally, the theoretically predicted relationships between the currents and voltages in case of two simple configurations of magnetic circuits. It also brings out the concepts of back electromotive force and reflected impedance. The problem also helps students develop different cognitive abilities like application, synthesis, interpreting, and inferring.

In this problem, as seen from the handout, students are given a detailed theoretical analysis for the currents and voltages in case of both the configurations of the magnetic circuits. The theoretical analysis also consists of different situations, which may arise with different loading at the secondary circuits. Students are given necessary information on the different instruments and apparatus, i.e. transformer boards, resistor ladders, rheostats, and digital millimeters in an instruction sheet. As seen from the handout, in this problem no questions are asked, but students are supposed to explore and verify the theoretically predicted relationships between different parameters. This experimental problem involves mainly investigation and partly exploratory type of practical work.

5.2.6 Demonstration No. 4

A) The objective

This demonstration is designed to serve as a prelude to the Experimental Problem No. 4. The format of presentation of this demonstration is same as that of the earlier demonstrations i.e. the instructor questions the students and presents the demonstration in an interactive manner. This demonstration involves mainly the observation type and partially the illustration type of practical work.

The demonstration uses a two loop magnetic circuit to explain how the changing magnetic flux linked with a coil gives rise to an induced emf. It also directly or indirectly explains the concepts like, magnetic flux, induced emf, magnetic circuit and the reflected impedance.

B) Brief description

The experimental setup essentially consists of a specifically designed three legged transformer in which two coils of copper wire each of 300 turns are wound on the central leg of the laminated iron core. The cross sectional area of the central leg is twice that of the extreme legs. One of the coils serves as the primary and the other secondary. This transformer is fixed on a wooden board and the connecting terminals for the coils are taken out. Three high watt fixed value resistors are provided, which may be used to limit the current in the circuit. A 6 *Volt*, 15 *Watt* bulb is provided with its connecting holder. An 18-0-18 *Volt*, 2 *Amp* step-down transformer is used to supply the necessary current in the primary circuit. In this demonstration, the circuit connections are made as shown in Fig.5.2.6. The primary coil is connected to an a.c. source (36 *Volt*) in series with a bulb and two resistors. Initially, we keep the points A and B unconnected and put

ON the power to the circuit. We observe that the bulb doesn't glow. We explain through questions, why the bulb does not glow, where the applied voltage gets dropped and the order of magnitudes of currents and voltages across the primary coils.

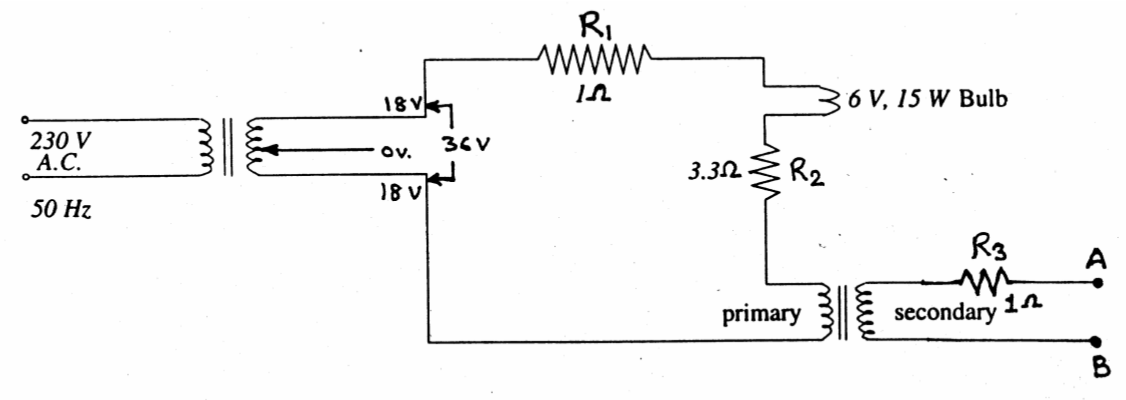

Fig 5.2.6 The circuit diagram

We then measure the induced emf (i.e. voltage) across the secondary coil. We find that this voltage is as large as the primary voltage.

We then short the secondary coil and find a glow in the bulb. We measure the currents and voltages in the primary and secondary circuits, and thus explain the concept of the back emf and reflected impedance. We also explain the dependence of the turns ratio of the primary and the secondary coil on the reflected impedance.

More information about the questions and explanations may be obtained from the instructors' handout given in the Appendix B.

5.2.7 Experimental Problem No. 5

A) Brief description

As we know a physical pendulum is an extended physical object of an arbitrary shape that can oscillate about a fixed axis. In case of a physical pendulum, the shape of the pendulum does not have to be regular. However, knowledge of the distribution of mass is essential since the center of gravity must be known. The physical pendulum used in this experimental problem consists of a cylindrical threaded brass rod (actually a long screw) and a square shaped nut. The pendulum is mounted on the knife-edges fixed to an aluminum stand. One can change and measure the distance x between the point of suspension and the upper end of the rod by turning the nut or the threaded rod.

In Part A of the problem, students are expected to study the variation of the time period of oscillations of the physical pendulum, with the variation of the distance of the axis of rotation from the center of mass of the pendulum. This distance is related to x.

Thus in this Part, students change the distance x and measure for various values of x the corresponding value of time period of oscillations T.

In Part B, students are expected to use the data recorded above and determine the local value of the acceleration due to gravity g. While determining g, students are supposed to take into account the correction due to the presence of the nut, because of which there is a slight shift in the position of the center of mass of the pendulum, as the distance x is changed.

In Part C, of the problem, the magnetic dipole moment of a small magnet embedded at the lower end of the pendulum, oscillating in a magnetic field, is determined by measuring its effect on the time period of oscillations of the pendulum. The given physical pendulum, with a small magnet embedded at its lower end is mounted on the knife-edges. Another strong cylindrical disc magnet is mounted on a vertically adjustable stand kept just below the equilibrium position of the pendulum. Because of the presence of magnetic field of the disc magnet, the pendulum experiences an attractive force, the effect of which gets added to the effect of acceleration due to gravity and thus the time period of the physical pendulum is decreased. This altered time period of the pendulum is measured for different distances between the two magnets, and thereby the magnetic moment of the magnet embedded at the lower end of the pendulum is determined.

B) Experimental arrangement

The complete experimental arrangement for this experimental problem is shown in Fig. 5.2.7. As described earlier, the physical pendulum used in this problem, consists of a cylindrical fully threaded brass rod and a square shaped nut. The pendulum can be mounted on the knife-edges provided on the aluminum stand. A small cylindrical magnet is embedded at the lower end of the pendulum rod. The axis of this magnet coincides with the axis of the pendulum rod and the density of the material used for the magnet is found to be very close to the density of the brass. Hence we found that actual center of mass of the rod coincides with the midpoint of the rod.

The time period of oscillations of the pendulum may be measured using the timer. The timer consists of a digital stop-clock, a control unit and a photo-detector. The photo-detector is mounted on the aluminum stand so that when the pendulum oscillates, the pointer attached to the square nut obstructs the light beam of the photo-detector, which supplies a necessary signal to the control unit. The control unit is programmed to display the time period for the third oscillation of the pendulum after resetting the timer.

Fig. 5.2.7 The complete experimental arrangement

A strong cylindrical disc magnet is fixed on a non-magnetic stand, the height of which can be changed either by adjusting the base table using an adjustable screw or more precisely by using the micro-stage with a micrometer screw. The micrometer screw may be used to measure accurately the distance between the lower end of the pendulum and the disc magnet. A set of acrylic discs and cylinders of different thickness is provided, which may be used as a reference for the measurement of the distance. A metallic cone is provided to adjust the position of the cylindrical disc magnet so that the axis of this magnet coincides with the axis of the pendulum, when the pendulum is in equilibrium position. A spirit level and a micrometer screw gauge are also provided.

C) Salient features

In this experimental problem, there is emphasis on the development of all three aspects of practical physics, namely, conceptual understanding, the laboratory skills, and procedural understanding along with different concepts of evidences. The concepts to be understood are the small oscillations, the physical pendulum, the moment of inertia, the parallel axis theorem, the magnetic field of a bar magnet along its axis and off the axis. The laboratory skills involved are of the type, handling or manipulation, adjustments, measurements, use of apparatus, alignment, judgment and control, and drawing graphs and tables. The concepts of evidences involved are more of design, measurement and data handling type.

In this problem, students are asked to estimate the error getting introduced in a derived variable on account of the errors or uncertainties in the individual measurements. This helps students develop the understanding of estimation of errors and importance of significant figures, while reporting the laboratory work.

In the handout of the problem, students are given a detailed theoretical basis of the experimental situation and the problem. They are supposed to understand this theory and apply it for the determination of the required parameter. The students are also given detailed instructions on the use of different instruments and about the experimental set-up in a separately provided instruction sheet. They are given almost all the necessary procedural instructions but are forced to think on different concepts of evidences and take decisions about the design, measurement and data handling. For example, no exact numerical value of the independent variable is suggested and students are asked to select a proper value to obtain the best result.

This experimental problem mainly involves inquiry and skills type of practical work, partially involves investigation type. From the handout it may be seen that students are supposed to answer six questions during their laboratory work on the problem. These questions are designed around plotting and interpretation of graphs, obtaining the required result from the graph, the conceptual understanding involved in the precautions to be executed while performing measurements and the application to a new experimental situation.

The digital timer used in the experimental problem has been designed and calibrated by the researcher. The calibration of the timing device was carried out using a highly accurate digital storage type oscilloscope. The frequency, its stability and the overall reliability of the crystal oscillator were studied. We found that the idea of introducing the magnetic interaction and measuring the effect of this interaction on the time period of oscillation of the physical pendulum is interesting and innovative. Even though a rigorous theoretical analysis of the problem may be complex, we have made some simplifying assumptions, using which the experimental problem has been successfully designed.

5.2.8 Demonstration No. 5

A) The objective

This demonstration is designed to serve as a complementary prelude to Experimental Problem No.5. It is presented in an interactive manner, like the earlier demonstrations. It involves illustration and observation type of practical work.

The demonstration illustrates the oscillations of a physical pendulum and explains the dependence of its time period on the distance between the point of suspension and the center of mass of the pendulum. It also explains how this period is altered in the presence of an external magnetic field for a 'magnetic' physical pendulum. This demonstration is thus designed to introduce, illustrate and explain the above-mentioned key concepts involved in the Experimental Problem No.5

B) Brief description

In this demonstration, the experimental arrangement consists of a physical pendulum (a solid brass sphere attached to one end of a solid cylindrical stainless steel (s.s) rod), which can oscillate about a given axis. The pendulum is supported on two pointed screws fixed to a C-shaped stand. A nut mounted on the pendulum rod rests on the screws. The nut may be clamped to the s.s. rod of the pendulum which can move up and down on the rod. This allows us to change the distance between the center of mass of the pendulum from the axis of rotation. A small cylindrical magnet is embedded in the brass sphere so that the axis of this magnet coincides with the axis of the cylindrical s.s. rod. We call this pendulum, a magnetic physical pendulum. A digital timer is provided along with a C-shaped photo-detector, which can be used to measure the time period of oscillations of the pendulum. Also provided is a strong cylindrical disc magnet mounted on a non-magnetic stand with an adjustable height. This magnet may be mounted below the equilibrium position of the pendulum and the magnetic field produced by this magnet is assumed to be uniform over a horizontal plane for some distance (20 *mm*), from the axis of the magnet. A 150 *mm* metal measuring scale and a one *meter* long measuring tape is provided to measure distance.

In this demonstration, first of all, the dependence of the time period of oscillations T of the physical pendulum on the distance l of the center of mass of the pendulum from the axis of rotation is observed and explained. For this we actually change the position of axis of rotation and hence change the distance l and measure corresponding time *T*. We then introduce the strong magnet below the pendulum. We observe that the time period of oscillations for the same distance *l*, changes with the introduction of the disc magnet. We explain the cause of this change. We then increase the gap between the pendulum and the magnet in uniform steps and study its effect on the time period of oscillations. We also observe that the change in the time period *T* is not linearly proportional to the gap between the pendulum and the magnet.

5.2.9 Experimental Problem No. 6

A) Brief description

In Part I of this experimental problem. Students are expected to study the motion of spherical ball rolling down on a straight plastic track with a U-shaped cross section, inclined at an angle by analyzing its position versus time behavior.

A two-meter long plastic track is mounted on an aluminum base; on this plastic track the spherical ball can roll down touching the edges of the track. A digital timer may be used to measure the time taken by the ball to roll through a prefixed distance. Students have to measure the time *t* the ball takes to roll through the different distances *S* for two different values of the angle of inclination of the track with the horizontal. From this data of *S* and *t*, the students are expected to study the motion with respect to its velocity and acceleration and determine the acceleration of the ball (which is a constant) for both the inclinations. They are also expected to take into account the rolling motion of the steel ball and determine the local value of acceleration due to gravity *g*. Also, they are supposed to estimate the percentage error in the values of acceleration of the ball and the acceleration due to gravity.

In Part II, of the experimental problem, the students are expected to study the motion of a freely falling spherical ball and determine the acceleration due to gravity *g*. In this Part, the students use a spherical steel ball for which the air resistance is very small and hence we neglect the air resistance. The students let the ball fall freely only under the influence of force of gravity. They record the time *t* the steel ball takes to fall through a prefixed distance *S*. Thus for different distances, the *S* and *t* data is recorded. From this *S* and *t* data, the students are expected to determine the local value of acceleration due to gravity *g*. They are expected to estimate the percentage error involved in the determination of the value of *g*.

B) Experimental arrangement

The complete experimental arrangement for Part I of the experimental problem is as shown in Fig. 5.2.9 (a).

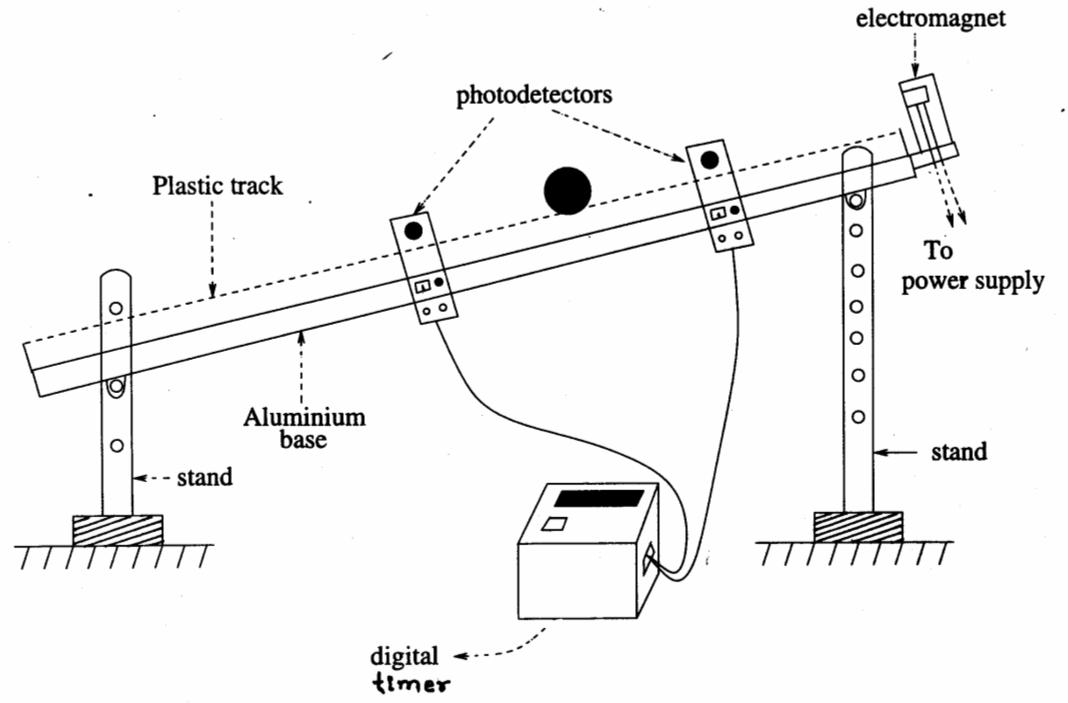

Fig. 5.2.9 (a) The complete experimental arrangement for Part I

In the experimental set-up a two-meter long aluminum base is mounted on two stands of different and adjustable heights so that the track makes an angle q with the horizontal. The inclination q may be changed by changing the height of the stands. A two-meter long U-shaped plastic track is fixed on this aluminum base. An electromagnet is fixed to one end of the track, which holds the ball and releases it from the same initial position each time. A d.c power supply is used to provide the necessary power to the electromagnet.

Two movable photo-detectors are mounted on the aluminum base. The position of the detectors, may be changed by moving the detectors along the length of the track and may be fixed using the screws on both the sides of the detectors. These detectors are connected to the digital timer. The digital timer measures and displays time the ball takes to roll down through the distance between the two detectors. The distance between the detectors may be adjusted and measured using a measuring scale fixed on the aluminum base and the wire (pointer) fixed on the detector. Students may keep the position of detector A (which starts the timer) fixed at a convenient distance from the electromagnet and change the position of the other detector B (which stops the timer), for the measurement of time for different distances. Two highly polished solid spherical steel balls are provided. Also provided is a meter scale and a measuring tape.

The experimental arrangement for Part II of the experimental problem is as shown in Fig. 5.2.9 (b)

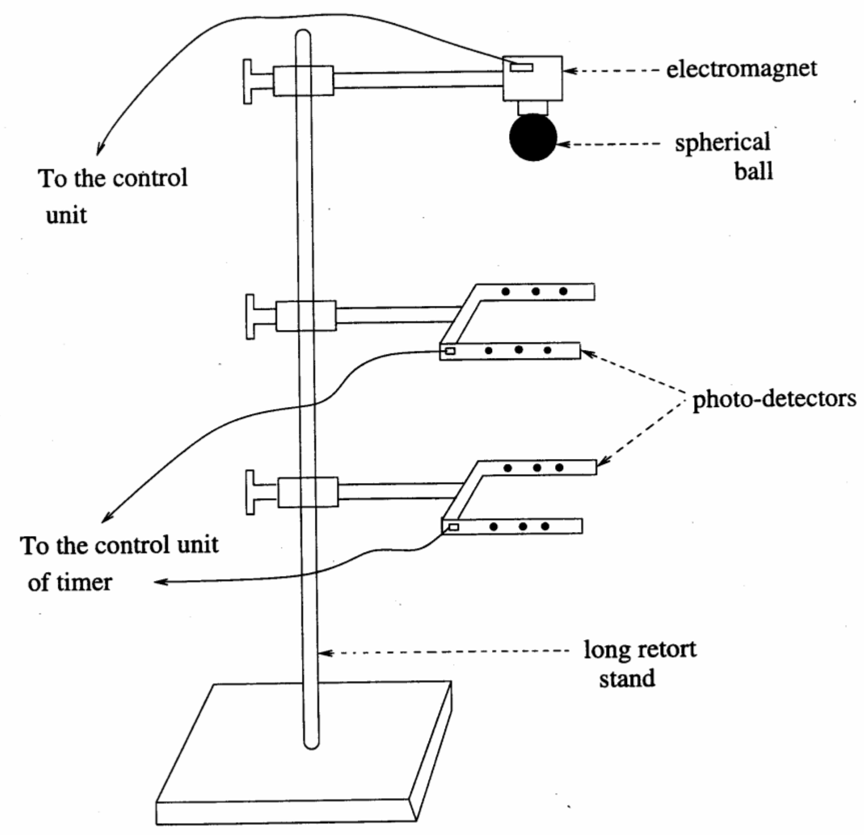

Fig. 5.2.9 (b) The complete experimental arrangement for Part II

The experimental setup consists of a long retort stand on the top end of which a small electromagnet is clamped, to hold the ball. Pressing of the switch of the control unit cuts off the power supply to the electromagnet and the ball gets released. The electromagnet is purposely used so that the ball gets released from the same position each time. For the measurement of time, a digital timer is provided which consists of a digital stop clock, a control unit and two C-shaped photo-detectors along with a frequency meter to calibrate the digital timer. The position of photo-detectors can be changed using a boss head and a clamp. Again in this case also, the detector A (which starts the timer) can be clamped just below the electromagnet and the other detector B (which stops the timer) can be clamped at any convenient distance from the detector A. The detectors detect the crossing of the ball and the digital timer displays the time the ball takes to fall through the distance between the detectors. Markings are made on the detectors, which can be used to measure the distance between the two detectors. A measuring tape is provided for the measurement of different distances.

C) Salient features

This experimental problem is designed to develop in students, mainly procedural understanding and concepts of evidence and partially laboratory skills and conceptual understanding. In this problem, the students are asked to estimate the error in the determination of a derived variable on account of the errors or uncertainties in the individual measurements. This helps the students develop understanding of error estimation and importance of significant figures. Some procedural instructions are given to the students through the handout. They are also given the information on the use of instruments, description of the apparatus, a brief the introductory theoretical basis of the problem.

In both the parts of the problem very little or no information is given about the concepts of evidence associated with measurement and data handling. The students are supposed to design the most accurate method to determine the value of a derived variable i.e. acceleration a or g. This problem also develops in students, different cognitive abilities like application, synthesis, interpreting and inferring. The laboratory skills involved are relatively simple and are of the type, handling or manipulation, measurements, use of apparatus, adjustments, alignment, judgment and control.

The conceptual understanding involved is simple and is mainly from mechanics, like motion of a spherical object on an inclined plane, rolling of a sphere, motion of a freely falling object, velocity, acceleration, damping, frictional forces etc.

As said earlier, in this problem there are two separate parts (Part I and Part II). In both the parts, the students are expected to study the motion of an object by understanding the distance and time behavior. They are expected to determine experimentally the value of acceleration due to gravity g along with the percentage error in the value of g. As seen from the handout the students are asked seven 'intermediate' questions. Most of these questions are designed around the concepts of evidence associated with data handling. They involve use of graphs, plotting of a graph, interpretation of the plot, and advantages of the graphical method to determine a derived parameter. There is a question on the estimation and minimization of errors in the result of an experimental problem. This experimental problem is mainly designed as a skill, observation and illustration type of practical work. It also involves partially the investigation type of activity. Thus the objective of this experimental problem is to develop 1) concepts of evidence associated with measurement and data handling 2) the understanding of estimation of errors and reporting of laboratory work 3) conceptual understanding and 4) the laboratory skills.

5.2.10 Demonstration No. 6

A) The objective

This demonstration is designed to serve as a prelude to Experimental Problem No.6. The format of presentation of this demonstration is the same as that of the earlier demonstrations except that, the number of questions asked to the students is less and more emphasis is given on the explanation by the instructor. This demonstration is designed as an illustration and observation type of practical work.

This demonstration is designed to introduce to students, the use of a new instrument, that is, a digital timer. The objective is to explain the use and principle of operation of a digital timer for measurement of the time interval between two events. The use of the timer is demonstrated in two different experimental situations. Also the mechanism of sensing the passing of ball through the photo-detector is explained and concepts like accuracy, precision, and calibration are discussed.

B) Brief description

In this demonstration the use of digital timer in two different experimental situations is explained. In case of the Parts A, B and C, the timer is used to measure the time a ball takes to roll down an inclined U-shaped plastic track for a prefixed distance. In Part D, the timer is used to measure the time the ball takes to fall freely through a prefixed distance, under the influence of the force of gravity.

In the experimental set-up for the parts A, B and C, a two-meter long aluminum base is mounted on two stands of different heights. A two-meter long U-shaped plastic track is fixed on this aluminum base. An electromagnet is fixed to one end of the track, which holds the ball. A d.c. power supply is used to provide the necessary power to the electromagnet. Two photo-detectors are mounted on an aluminum base, which can move along the length of the aluminum base. These detectors are connected to the digital timer. The digital timer measures and displays the time the ball takes to roll down through the distance between the two detectors. In Part A, the use and adjustments of the detectors and the timer is demonstrated and through a question the principle involved in sensing the passing of a ball through the photo-detector is explained. Then the time measurement is repeated for three to four times keeping the photo-detector arrangement and the inclination the same. Using this data the concepts of accuracy, precision and calibration are explained. Students are also explained the method of calibrating the digital timer.

The experimental arrangement for Part D, of the demonstration consists of a long retort stand with a heavy base on which an electromagnet and two G-shaped photo-detectors are clamped. In this case each photo-detector consists of three photo-gates or photo-pairs, i.e., a pair of an LED and a phototransistor (unlike the earlier case where there is only one photogate in each detector). This is done to increase the sensitive area of the detector. The detectors are properly aligned and connected to the digital timer. The ball is attached to the electromagnet and then released electronically. The ball falls through the two detectors and crosses their sensing area and the timer displays the time interval between the crossings of the ball through the two detectors. This measurement is repeated for different distances between the two detectors and thus the use and principle of working of the digital timer is explained.

5.2.11 Experimental Problem No. 7

A) Brief description

We found that, in the field of electricity and magnetism, one of the most difficult problem for students is the visualization of *lines of forces* and the *equipotential surfaces*. In this experimental problem, we study the nature of electrostatic potentials and the equipotential surfaces for various electrode configurations. For this an electrolytic tank is used, in which the electrodes of different shapes may be arranged. By applying the potential difference between the electrodes, an electric field is constructed inside the tank as an alternating current field. The equipotential curves are studied with the only condition that there is symmetry along the vertical axis. For plotting the equipotential curves, students are expected to identify the locus of points, which lie at the same potential with respect to the reference. The potential distribution can be compared with the solution of Laplace equation (in two dimensions) for the specified configuration and conditions.

Students study the equipotential curves for geometries like 1) two parallel plates 2) one point electrode placed on the angle bisector of a L-shaped electrode and 3) two concentric cylinders. Using the two concentric cylinders, students are expected to study the uniqueness theorem. Also the technique of method of images is to be studied by using the equipotential curves for a point electrode placed in front of a long conducting metal plate.

B) Experimental arrangement

The experimental arrangement for this problem is very simple. It consists of a specially designed acrylic tank (of dimensions 50 x 75 x 7 *cm*). This acrylic tank has a thick and hard base plate on which a large laminated graph paper is pasted. The tank is properly leveled using the acrylic bushes fixed at its bottom. An electrolyte prepared dissolving some potassium chloride (KCL) in water is introduced in the tank. The electrolyte may fill the tank up to half of its height. This electrolyte provides a low resistance path for the current, when the metallic electrodes of different shapes are placed in the tank and an a.c. potential difference is applied between them.

A set of metallic electrodes is provided. This set consists of plates, hollow cylinders, solid cylinders and L-shaped electrodes. The solid cylinder (actually a s.s. rod) may be treated as a point in two dimensions. A digital multimeter is provided along with the probes, which is to be used for the measurement of potential difference. A variable a.c. (50 *Hz*) power supply is provided which has outputs in steps of 1.5 *Volt* up to 9.0 *Volt*, and then the 12 *Volt* output. This power supply is used to establish the necessary potential difference between the electrodes. Two variable resistors are available, which may be used to adjust the potential applied at different electrodes. Also provided are connecting wires and a measuring tape or measuring scale.

C) Salient features

This experimental problem emphasizes the development of conceptual understanding much more than the development of procedural understanding, understanding of concepts of evidence and the practical skills. This problem is designed to explain to the students, the concepts like, the lines of force, equipotential curves or surfaces, and the uniqueness theorem. It also illustrates the principle of method of images, which is one of the most useful technique in electrostatics for predicting the field lines or the equipotential curves for complex distribution of charges. In this experimental problem students plot the equipotential curves for different electrode configurations and develop an understanding about the method or the technique of plotting equipotential curves. The power of this method is in arriving at the euipotential curves for an arbitrary electrode configuration for which a simple analytic solution of Laplace equation cannot be easily obtained. Students are given information on the use of the instruments like, digital multimeter, a.c. power supply. In this problem, as seen from the handout in the appendix, four questions are asked. All the four aim to develop conceptual understanding. Out of these four questions, three require students to predict the expected equipotential curves or the alteration in the observed equipotential curves. The fourth question is based on the uniqueness theorem.

This problem helps students to develop a link between the theory and the experiment. Here students are expected to compare the experimentally observed equipotential curves with the theoretically predicted curves. This experimental problem mainly involves the exploratory and verification type and partially involves investigation type of practical work. It develops relatively simple and less complex concepts of evidences and laboratory skills. The laboratory skills involved are of the type handling and adjustment, measurements, use of apparatus, alignment control and drawing graphs. The concepts of evidences involved are of the type, which are associated with the measurement and data handling.

Thus this experimental problem is mainly designed to develop in students the conceptual understanding related to the introductory concepts in electrostatics and to introduce an innovative technique for plotting equipotential curves.

5.2.12 Demonstration No. 7

A) The objective

This demonstration is meant to serve as a prelude to the Experimental Problem No.7. The objective of this demonstration is to explain to the students 1) the experimental arrangement with its basic necessities, 2) the method or technique of plotting the equipotential curves using the electrolytic tank and 3) the equipotential curves for a dipole geometry. This helps students visualize the lines of force for a dipole geometry. This demonstration is also presented in an interactive manner and is designed as a skill, illustration and observation type of practical work.

B) Brief description

The experimental arrangement for this demonstration is identical with that of the experimental problem. The set-up consists of a specially designed acrylic tank of dimensions (50 x 75 x 7 *cm*). This acrylic tank has a thick base plate on which a large laminated graph paper is pasted at its bottom. The tank is properly leveled using the acrylic bushes fixed at its bottom. In this tank an electrolyte solution is prepared using potassium chloride (KCL) and water. This electrolyte fills the tank up to half of its height. A set of three identical metal solid cylindrical electrodes (actually stainless steel rods) is provided. A digital multimeter is provided along with the probes, which is to be used for the measurement of a.c. voltage (i.e. the potential difference). A variable a.c. (50 *Hz*) stabilized power supply is provided which has fixed outputs in steps of 1.5 *Volts* up to 9 *Volts* and then the 12 *Volts* output. This power supply is used to establish the necessary potential difference between the electrodes. Also provided are connecting wires and a measuring tape or measuring scale.

In this demonstration, first the instructor explains the experimental arrangement along with the finer adjustments and precautions to be executed. The experimental arrangement necessary for plotting the equipotential curves for a dipole geometry is shown. Then the method or the technique (which is to be used in experimental problem) for plotting the equipotential curves is explained and demonstrated. Also the proper method of using the digital multimeter and the power supply is explained to the students.

Through this demonstration, some simple questions about the method and the arrangement are answered. Also the students are asked to draw the expected eqipotential curves for the dipole geometry of electrodes. Actual measurements are done and by finding the locus of points, which lie at the same potential, equipotential curves are drawn for the dipole geometry.

More information about the questions, explanations and the instructions may be obtained from the instructor's handout given in the Appendix B.

5.2.13 Experimental Problem No. 8

A) Brief description

We know that, ordinary light sources emit unpolarized light, which means that in the case of such light the electric vectors are oriented in random directions, uncorrelated with each other. Light in which all the photons have their electric vectors oriented in the same direction is called the plane-polarized light. The polarization of light may be achieved using different methods. In part A and B of the problem, students are expected to first determine the transmission axes of the given polarizer and analyzer using a reference polarizer for which the transmission axis is known. This is achieved by a comparison method and plotting a graph. In part C, the students are expected to study the relationship between the intensity of light incident on the photo-detector and its output current for any one of the given photo-detectors. They use the law of Malus for this purpose. They are expected to plot an appropriate graph to explain the observed relationship. Actually, for the given photo-detector, there is a linear relationship between the light intensity and the output current, for the given range of intensities.

In part D, the students study the reflection of polarized light from the surface of a transparent prism. In this they use the plane-polarized light with the direction of polarization (i.e. direction of E-vector) parallel to the plane of incidence (i.e. say, P-component) and study the variation of reflectance or reflectivity with the angle of incidence. From this using the Brewster's law, they are expected to determine the refractive index of the material of the prism.

Then in Part E, too, the students are expected to study the variation of reflectance or reflectivity for the surface of the prism, with the angle of incidence, but in this case, for a plane polarized light with the plane of polarization perpendicular (i.e. normal) to the plane of incidence (i.e. say S-component)

B) Experimental arrangement

The experimental arrangement for parts A, B and C is very simple. In this, a red He-Ne laser source, a polarizer, an analyzer and a photo-detector all are mounted on the optical bench. The laser beam passes through the polarizer, the analyzer and is then incident on the sensitive area of the photo-detector. A digital multimeter is used to measure the output current of the photo-detector.

For part D and E, the experimental arrangement is as shown in Fig. 5.2.13.

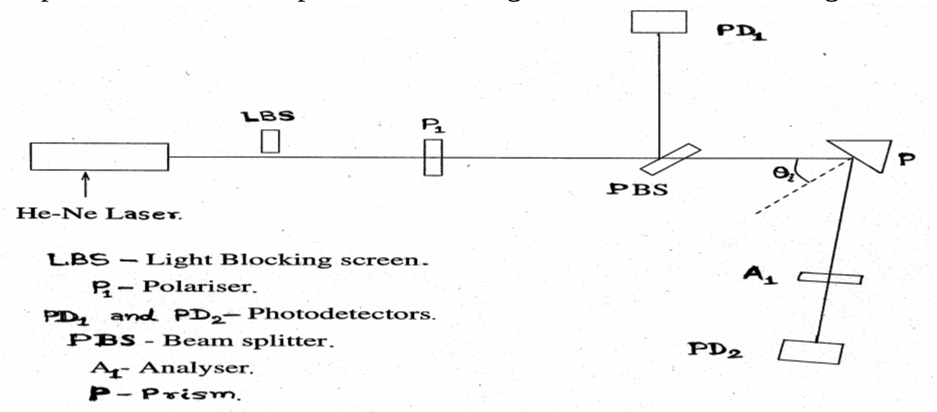

Fig. 5.2.13 The schematic of the experimental arrangement

A He-Ne laser source is mounted on a stand with adjustable height. The light emitted by the laser source is unpolarized. A light-blocking screen is provided which can be used to block the laser beam whenever it is not necessary. This light-blocking screen is mounted on an optical bench. The polarizer is used to polarize the light with the plane of polarization in a particular direction. The polarizer is mounted on a holder with markings on a vertical circular degree scale disc, which may be used for the adjustment and the measurement of angles. Also, an extra reference polarizer is provided for which the transmission axis is known.

A plane beam-splitter is clamped on a holder and is mounted on the optical bench. The beam splitter is used to split a single laser beam into two beams. The angle of incidence should be exactly 45 degree for the beam splitter to reflect 50 % intensity and transmit 50 %. A photo-detector is used to monitor the variation of the intensity of light reflected from the beam splitter. This is necessary because the output power of the laser source may fluctuate from time to time, and needs to be monitored and requires appropriate correction in the calculation of the experimental results.

A right angle glass prism is mounted on a holder, which is fixed to the prism table of the diffractometer arrangement. This holder is provided with a universal tilt mechanism. Using the two leveling screws this holder may be leveled and aligned properly. The height of this holder may be changed. This prism holder is fixed to a horizontal circular degree scale, which can be rotated. An analyzer and a photo-detector are mounted on the circular moving arm of the diffractometer arrangement, which is basically spectrometer but without the collimator and telescope arms. One may use the scale on the central circular portion of the diffractometer arrangement to measure angles more accurately. The analyzer is used to study the state of polarization of light reflected from the surface of the prism. The photo-detector is used to measure the intensity of reflected light. Both the photo-detectors have identical characteristics. Two identical digital multimeters are used to measure the output currents of the photo-detectors. Also provided are a magnifying reading torch, a spirit level and lens cleaning tissues.

C) Salient features

This experimental problem is designed around the concept of polarization of light by a reflection from the surface of a transparent medium. In this problem, the students are given preliminary tasks in which first they determine the unknown transmission axes of the given polarizer and the analyzer. Also they study the relationship between the intensity of light incident on the photo-detector and its output current. Then they study polarization of light by reflection from the surface of a transparent prism.

In this problem, all the three aspects, i.e. conceptual understanding; procedural understanding, and concepts of evidence and laboratory skills are equally important and hence are equally emphasized. The problem is designed to develop in students all the three aspects. The conceptual understanding here pertains to concepts from optics, particularly, from polarization of light. The main concepts and laws involved are, polarization of light, characteristics of light emitted from a laser source, intensity, plane of polarization, plane polarized light, polarization by reflection, law of Malus and Brewster's law.

Procedural understanding and concepts of evidences associated with design, measurement, data handling and analysis are more emphasized in this problem. The laboratory skills involved are of types handling or manipulation, alignment or judgment, use of instruments and tools, measurement and control, drawing graphs and observation tables. This problem also helps students in the development of different cognitive abilities like designing, application, synthesis, interpreting and inferring.

In this problem, students are given detailed instructions on the use of apparatus and tools; this includes information on the use of He-Ne laser source, diffractometer arrangement, beam-splitter, photo-detector and a pair of polarizer and analyzer. Some introductory procedural instructions are given to the students through the handout, which carries very little information on concepts of evidence. Four questions are included in the handout. Q.1 is designed to check the understanding of appropriate use of a graph and drawing conclusions from the graph. Q.2 is also based on plotting of a graph, and on the ability to choose appropriate parameters or quantities to be plotted making use of the theory to the problem. Q.3 again is designed around the plotting of graphs but the importance is given to the ability of explaining the observed relationship from the graph. Q.4 is designed to develop an ability of comparing two curves and drawing inferences from the comparison. This experimental problem is designed around mainly the illustration, skill and investigation type of practical work.

5.2.14 Demonstration No. 8

A) The objective

This demonstration is designed as a prelude to the Experimental Problem No.8. It is designed with two objectives, the first is to introduce to students use of different instruments and optical components and explain related precautions and the second is to demonstrate polarization of light (emitted by a laser source) after a reflection from the surface of a transparent prism. This demonstration directly or indirectly explains different concepts involved in the problem. This demonstration is presented partially in an interactive manner and is designed around the illustration and observation type of practical work.

B) Brief description

In part I of this demonstration, the use of different optical components (along with their mounts) and instruments is illustrated and explained to the students. The students are supposed to use these optical components and instruments in the experimental problem. We find that they hardly know anything with respect to the method of operation and use of these components and instruments, and also the necessary precautions to be exercised. These components and instruments include a He-Ne laser source, diffractometer arrangement, plate beam splitter, photo detector and an analyzer-polarizer pair. In case of each of these components the demonstration explains the use, specifications, method of operation and the necessary precautions along with the mounting instructions.

In part II of the demonstration the concept of polarization of light is explained and the polarization of beam of unpolarized light emitted by as the laser source after a reflection from the surface of the prism is demonstrated. In this the unpolarized light emitted by a laser source is incident on the surface of the transparent prism at different angles of incidences and the state of polarization of the reflected light is studied using an analyzer and a white screen. The state of polarization of reflected light when the light is incident at Brewster's angle is also demonstrated.

More information about the questions and their explanations along with the other details of the demonstration may be obtained from the instructors' handout given in the Appendix B.

5.2.15 Experimental Problem No. 9

A) Brief description

As we know, in the case of formation of primary rainbow, the sunlight incident on a raindrop is refracted at the first surface, reflected at the back surface and refracted again as it emerges in to the air. Dispersion occurs as the sunlight propagates through the drop. When this process occurs in a large number of raindrops, a primary rainbow is produced in the sky. A secondary rainbow occurs with two internal reflections.

When the white light is incident on a suspended drop of a liquid, the suspended drop will produce different order rainbows as a result of two refractions and K (K = 1, 2, 3, ...) internal reflections of light. The first order rainbow corresponds to one internal reflection. The second order rainbow corresponds to two internal reflections. Thus the K^{th} order rainbow corresponds to K internal reflections. Each rainbow is due to white light rays incident on the drop at a well determined angle of incidence, which is different for each rainbow. Each rainbow contains all the colors of the spectrum of the incident white light.

In this experimental problem, students are expected to study the different order rainbows formed in a drop of different given liquids. In part I of this problem, students are expected to study the formation of different order rainbows in a suspended drop of water and measure the angular positions of different order rainbows. These rainbows can be observed directly by the eye and their angular positions can be accurately measured using the telescope in conjunction with the spectrometer's circular scale. From this, the variation of total deviation of the incident light for different orders with the number of orders is determined and studied.

Also, as we know the deviation of light, when light enters in a medium of refractive index m is proportional to m and the wavelength of light l. In part II of the problem, the students are expected to obtain the rainbows with different liquids and measure the deviation for a second order rainbow for different liquids. Then by comparison method, the students are expected to determine the unknown refractive index of the given liquid A.

B) Experimental arrangement

In this experimental problem, the students are given a high power (150 *Watt*) tungsten filament bulb as a source of white light. This bulb is mounted inside a wooden box. Four windows are provided to take out the desired amount of light. The height of these windows may be adjusted as required. A cooling fan is fixed inside the box to avoid any damage to the box by excessive heating. A power supply is used to provide the necessary power to the tungsten filament bulb. This power supply has one common and five variable output terminals. The intensity of light emitted by the bulb may be changed by connecting the bulb to different output terminals of the supply.

A spectrometer is provided with a circular degree scale disc and two windows for measurements of angle. In this case, the mounting of the collimator arm is modified to increase the range of movement of the telescope arm. The collimator has adjustable slits on both the sides along with the regular lens arrangement. This is used to illuminate only half of the liquid drop. The telescope does not have the regular lens arrangement, instead, the eyepiece is replaced by a pinhole and the objective is replaced by a magnifying lens of suitable focal length. This is done to get the magnified image of the liquid drop.

A specially designed syringe holder is provided to hold the syringe in the symmetric position. This holder is mounted on the prism table. The holder is so designed that when the syringe is properly clamped and the liquid drop is obtained, the drop is seen from all angular positions of the telescope and that also exactly at the center of the field of view of the telescope.

A set of four syringes, small beakers and pettri dishes is provided. Beakers are used to keep different liquids. Pettri dishes can be mounted on the plane platform of the prism table and used to collect the liquid, which trickles down from the syringe. Four different liquids, i.e. water, glycerin, clove oil and liquid A, are provided. A magnifying reading torch is provided, which may be used for reading the circular scale.

C) Salient features

This experimental problem is designed to explain the formation of different order rainbows on the basis of reflection, refraction and dispersion of light when it is incident on a suspended drop of liquid. In this problem the development of conceptual understanding and the laboratory skills are more emphasized than the procedural understanding and the concepts of evidences. The conceptual understanding involved is from the field of optics like reflection, refraction, dispersion of light, refractive index, wavelength of light etc.

The laboratory skills involved are of the type alignment, judgment, use of apparatus, handling and manipulation, measurement and drawing graphs. The procedural understanding and the concepts of evidences involved are associated with measurement and data handling.

In this problem, the theoretical basis of the formation of rainbows is explained to the students through the students' handout. The students are also given instructions on the use and alignment of the tungsten filament bulb, its power supply and the spectrometer. Some instructions on procedural aspects and concepts of evidences are given to the students. This is intentionally done since the procedural understanding involved in this problem is relatively simple and hence not given an important place as compared to the conceptual understanding and the laboratory skills.

In this problem, four questions are asked to the students. These questions are mainly designed around the development of abilities related to the plotting of graphs, explaining the observed behavior through the graph, choice of proper parameters to be plotted (on the basis of the theoretically expected results) to get the desired results, estimation of errors and application of the understanding to design a new situation for the required purpose or the task.

This problem is designed mainly around skill and illustration and partially around investigation type of practical work.

5.2.16 Demonstration No. 9

A) The objective

This demonstration is meant to serve as an introduction or a prelude to Experimental Problem No.9. In this demonstration, the use of apparatus is explained and demonstrated to the students and hence this has less interactive component, but the format of presentation is identical to the earlier demonstrations. This demonstration is designed around illustration and observation type of practical work.

In this demonstration the use of a spectrometer is demonstrated and explained. In the experimental problem we use a spectrometer, in which the regular arrangement of the collimator, telescope and prism table is modified. This modification is explained to the students. The demonstration explains the concept of least count, and the necessary adjustment and alignment of the source of white light, the collimator, the liquid drop and the telescope. How to use the adjustable slit to illuminate half of the liquid drop is shown and finally the different order rainbows in case of the water drop are demonstrated to the students.

B) Brief description

In part A of the demonstration, the students are shown a regular spectrometer and also the given modified spectrometer. They are then introduced to the use of spectrometer, its main parts with their uses, optical components used and the method of measuring angular position of the telescope. Then the modification incorporated in the given spectrometer is shown and explained to the students along with its need. Also the use of this modified spectrometer is explained.

Question one is introduced to explain the concept of the least count of a measuring instrument. In part B of the demonstration, the alignment and adjustment necessary for observing the different order rainbows is explained. In part C, the different order rainbows formed due to a water drop are demonstrated to the students; the angular positions of these rainbows, the observed spectrum, the position of red and violet ends and the relative intensities are also shown.

More information on this demonstration giving finer details may be obtained from the instructors' handout given in the Appendix B.

5.2.17 Experimental Problem No. 10

A) Brief description

When light from a distant source (or a laser source) passes through a narrow slit and is then intercepted by a viewing screen, the light produces on the screen a diffraction pattern. This pattern consists of a broad and intense central maximum and a number of narrower and less intense maxima on both the sides. In between the maxima are the minimas. A similar diffraction pattern may be observed using a plane diffraction grating. In case of the diffraction grating, the maxima produced are intense and widely separated.

In this experimental problem, the diffraction pattern observed due to a plane diffraction grating is observed and analyzed to determine the wavelength of the light emitted by the laser source. A precision circular aperture is used to study the diffraction pattern due to a circular aperture. In this case, the diameter of the circular aperture is to be determined.

A two-dimensional plane diffraction grating (which is actually a combination of two, one dimensional plane diffraction gratings) is used to get a two-dimensional diffraction pattern. Using the appropriate formulas, the grating spacings (i.e. the distance between two consecutive lines or slits) of both the gratings are to be determined. Also the angle of inclination between the two gratings is to be determined.

B) Experimental arrangement

The experimental arrangement consists of a 2-meter long optical bench along with four mounts. Different optical components can be mounted on these four mounts. A

He-Ne laser source may be mounted on one of the mount, preferably on the extreme left mount. Other three mounts may be used to clamp, either the diffraction grating, the light blocking screen, the precision circular aperture or the white screen. The position of any of the mounts may be changed along the length of the optical bench. A micro-stage is provided for each mount to change its position in a direction perpendicular to the length of the optical bench. One can use a measuring tape to measure the distance between the optical components and the screen.

Four plane diffraction gratings with different grating spacings are provided. Also provided are two 2-dimensional plane diffraction gratings, which are made by combining two independent one-dimensional plane diffraction gratings. A white screen is provided to observe and record the diffraction pattern. Two precision circular pinholes are provided. These pinholes are mounted on the holders, which can be directly clamped to the mounts of the optical bench. A light-blocking screen is used to block or interrupt the laser beam when it is not required. A 5 *meter* long measuring tape, a 30 *cm* measuring scale and a traveling microscope is provided, which may be used appropriately (if justified) to measure the different distances. A magnifying reading torch is provided to record and note down the readings.

C) Salient features

This problem is designed to study and analyze the diffraction of light (emitted by a laser source) by one dimensional plane diffraction gratings, a circular aperture and a two-dimensional plane diffraction grating.

In this problem, the development of all the three aspects i.e. conceptual understanding, procedural understanding (and concepts of evidences) and the laboratory skills is equally important and hence this problem is designed with an objective to develop all these abilities and understandings in students. In this problem, students develop an understanding about the diffraction of light due to plane diffraction grating, a circular aperture and a 2-dimensional plane diffraction grating. The procedural understanding and the concepts of evidence involved are simple but important to be developed and are associated with design, measurement and data handling. This problem help students to develop different cognitive abilities like application, interpreting, designing and inferring. This problem has more stress on laboratory skills like, handling or manipulation, adjustment, measurement, use of apparatus, alignment, judgment and drawing graphs and tables. In this, the estimation of errors and other related aspects is also emphasized and students are asked to determine the error and discuss the sources of errors and precautionary measures to minimize these errors.

In this problem, the necessary theoretical relations are given to the students. Instructions on the use of different apparatus are provided to the students through the instruction sheet. Also some simple instructions on the procedural aspects and concepts of evidences are given. Five questions are asked, which are designed around the understanding about plotting of graphs, estimation of errors, procedural understanding and the application of the conceptual understanding in a new situation to predict the unseen pattern or effect.

This experimental problem is designed around skills, illustration and investigation type of practical work.

5.2.18 Demonstration No. 10

A) The objective

This demonstration is designed as a prelude to Experimental Problem No.10. This demonstration explains the diffraction of light emitted by a laser source using a single slit and a plane diffraction grating. The objective of the demonstration is *i*) to explain the characteristic properties of light emitted by a laser source. *ii*) to introduce and illustrate the concept of diffraction due to a single slit and a plane diffraction grating and *iii*) to observe the diffraction pattern due to different plane diffraction gratings and explain the dependence of angle of deviation q_m corresponding to different maximum intensity points for different orders on the grating spacing. *d*. This demonstration also explains the idea of 2-dimensional diffraction.

This demonstration is presented in an interactive manner and is designed around illustration and observation type of practical work.

B) Brief description

The experimental set-up for this demonstration consists of a 2-*meter* long optical bench with four mounts. These mounts can be moved along the length of the optical bench and thus can change the position of different optical components mounted on them. A red He-Ne laser source is clamped on one mount and other three mounts can be used to clamp any of the optical components. A holder is provided to mount different gratings. A white screen is provided to observe and record the diffraction pattern.

First of all, the students are introduced to the new device i.e. a laser source. The difference between the light emitted by a laser source and a mercury vapor lamp is explained. A single slit (with adjustable slit width) is introduced in the path of the laser beam. The diffraction pattern obtained on the white screen due to this single slit is shown to the students. Also some basic information about the intensity distribution in the diffraction pattern is given to the students. Also the variation of the angular position of m^{th} order minimum with the slit width is explained and demonstrated.

The diffraction due to a plane diffraction grating with 15000 lines per inch (LPI) is demonstrated and explained with respect to the angular positions of different order maximas. Also how the diffraction pattern gets altered when the above grating is replaced by a grating having 6000 LPI (and also the gratings having 2500, 300 LPI) is demonstrated. The principle of obtaining the two dimensional diffraction pattern is illustrated and explained.