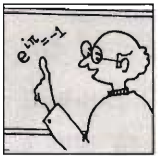

In this section of* Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

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Simple, Concept-Centred, Innovative, Open-Ended Experiments in Physics – 1

Kishore Vaigyanik Protsahan Yojana (KVPY) is a programme sponsored by DST and administered by Indian Institute of Science, Bangalore, to attract young talented students to science. It has been running since 1999. The fresh awardees every year are invited to IISc for a Summer School. This year, in May 2002, for the first time the Summer School had an experimental component, and we were asked to give the experimental laboratory programme in physics. The first part of this article describes briefly the five experiments which we presented in the lab component. The next part will describe five more experiments. All the experiments are simple and do not require any sophisticated equipment. The article is based on the write-up distributed to the students.

Introduction

There is a common complaint all over the country that the number of bright students opting for basic science as a career is dwindling. We have been engaged in undergraduate and postgraduate teaching for the past several decades, and have also been associated with the admission process. We are aware of student preferences from different parts of the country. While it

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is true that a vast majority of students look for quick job placements and material benefits, there is a small section of students who are willing to sacrifice such lucrative careers for the sake of excitement and challenge. But the pity of the present-day teaching is that even these are missing at the higher secondary and undergraduate levels.

The aim of the experiments was to show that physics is not confined to classrooms and blackboards.

We have found that simple and innovative laboratory experiments, with applications in real-life situations, are able to create this excitement among students, and show the challenge involved. The aim is to show that good physics is not confined to classrooms and blackboards. We have developed a large number of such low-cost experiments, and also some very dramatic demonstrations, with apparatus which is readily available in a college lab, and does not require any additional sophisticated equipment. Our experiments require only wires, magnets, springs, meters, ICs, balls, prisms, lenses, stands, plastic tubes, CRO, current and voltage supplies, signal generator, photodiode, 2-mW laser, and such other items.

The KVPY Summer School 2002

Kishore Vaigyanik Protsahan Yojana is a scheme sponsored by the Department of Science and Technology (DST) to attract young talented students to science, which has been in operation since 1999. It is administered by the Indian Institute of Science (IISc), Bangalore. Students are selected after Classes X and XII and given scholarships. They are also invited for a summer school, and the summer school for fresh awardees every year is held at IISc. In earlier years, the programme consisted of lectures and visits to various departments and institutes. In May 2002, for the first time, an experimental lab component was given to the KVPY scholars. There were 46 students who had come after their Class XI and 7 after their First Year of BSc examinations. Our team laid out ten experiments in a lab, which the students performed in groups of 4 to 6. A short handout was given to the students, which described the experiment and the activity in one page each. The students were able to do 6 to 8 experiments in the time slot that was available. They took readings, changed parameters, made calculations and drew inferences. Since the experiments were open-ended, the students got to see something beyond their prescribed syllabus. They soon started asking questions such as what will happen if this is done that way, etc. Their faces were lit with excitement. For us too the interaction with KVPY scholars was very rewarding.

It appears from the students' feedback that they highly appreciated this component. They have in fact made comments such as more time should have been given and the groups should have been smaller, etc. It was therefore felt that these experiments should be more widely known. They can be easily replicated anywhere. It is only a question of dissemination and somebody out there taking just a little more interest.

What follows are pages from the handout given to the students, suitably modified to fit into the format of an article. Although we have developed quite a few such experiments, we hope that these ten will serve as illustrative examples.

Experiment 1. *Head-on Collision of Bodies with Different Mass Ratios*

This is a topic in Class XI Physics. The teacher derives equations on the black-board, but doesn't show any demonstration. Experiments are also difficult because of friction, and need costly equipment such as linear air track, photosensors, and timers, etc. We perform this experiment in the vertical direction with balls where all the difficulties get solved. It was recently reported in this journal (*Resonance*, Vol.7, No.6, p.67, 2002); hence details are not given here.

Experiment 2. *Study of Projectile Motion using a Pistol*

You can study projectile motion by firing a single bullet with a suitable mass at different angles between 0° and 90°. Measure the range for various angles α of firing. Ensure that the bullet always lands on the table. Find the angle at which the maximum range is obtained by plotting a graph of 2α versus R, the range of the bullet.

Next, remove the pistol from the table and attach it to a laboratory stool. Take the stool close to an accessible wall/partition. Adjust the distance between the stool and the wall to be $R/2$ for every angle for which range was recorded earlier. Fire the bullet at the wall and carefully mark the spot where the bullet hits the wall. Hence measure the maximum height H attained by the projectile with reference to the plane of projection at various angles. If v is the initial speed of the bullet when it is fired, we have

$$R = v^2(\sin 2\alpha)/g, \quad H = v^2(\sin^2\alpha)/2g.$$

Since the initial speed with which the bullet is fired is the same at all angles, we can eliminate α to find

$$v = [(R^2 + 16H^2)/8H]^{1/2}.$$

Thus measuring R and H allows us to determine the initial speed v. The time of flight can also be obtained as

$$T = [8H/g]^{1/2}.$$

From your observations, you can determine the average speed v and hence the kinetic energy $mv^2/2$ of the bullet. Since this comes from the potential energy of the spring in the pistol that is equal to $Kx^2/2$, you can estimate the force constant K of the spring by measuring the extension x (assuming that the potential energy would be completely converted into the kinetic energy of the bullet), which is a constant for a given pistol.

How would you check if your estimate of K is reliable? In reality, both air drag and friction affect projectile motion. To know more about their role, you can perform the following activities.

1. Attach the pistol with boards close to a retort stand.

2. Attach a small hanger with suitable weights to the piston of the pistol and measure the extension produced.

3. Plot a graph of force vs extension to determine K of the spring. The value obtained using this method would be different from

the one obtained assuming complete conversion of potential energy of the spring into kinetic energy of the bullet. The difference must be attributed to frictional forces alone, since there is no air drag involved in this method.

4. Use a spring taken out of a similar pistol. Attach suitable weights to it by hanging it on a stand. Determine K again from the graph of force vs extension produced. The value of K obtained from these measurements would be closest to the real value since both friction and air drag have been eliminated.

5. Hence estimate the energy lost due to air drag and frictional forces.

Food for thought:

What are the presumptions made in various phases of the experiment?

What are the difficulties posed in measuring variables involved and how do we overcome them?

Can we estimate the reliability and accuracy of our measurements? Deduce the unconventional formulae used in this experiment from the known ones.

Experiment 3. ***Study of Friction using a Record Player***

This experiment will help you in estimating the force of friction in different situations. You have been given an old record player with multiple speed settings in RPM (revolutions per minute). Before you begin your study of friction, check if the speed settings are correct using the stroboscopic disc provided. Can you guess the precaution to be taken while checking the speed?

Select any of the discs specially made to study the force of friction between the material of a carrom striker and the disc. Place the striker closest to the axis of rotation and set the turntable rotating at 78 RPM. See if the striker maintains its position on the disc. If it doesn't, switch over to the immediate lower speed, viz. 45 RPM. If it does, stop the turntable, move the striker radially outward through one cm and restart the rotation. Check again if the striker retains its position or is thrown off the disc.

Use this procedure to determine, as accurately as possible, the critical radial distance r of the centre of the striker from the axis of the turntable. Then we can apply the equation $mv^2/r = \mu mg$, where m is the mass of the striker, g acceleration due to gravity, v the linear speed with which the striker rotates and μ the coefficient of static friction for the materials under study. Note that although m cancels out from both sides of the equation, it would show its adverse influence if we don't account for its limits. The rotation speed would reduce appreciably if m is very high and our calculations would need corrections. Since v is the critical linear speed, and $v = r\omega$, where r is the critical radial distance when the striker just slips, be careful to measure r accurately. Change over to a lower value of speed setting of the player, if possible. It would help you increase the accuracy. Note that every revolution corresponds to 2α radians and ω is to be measured in radians per second. Thus if n is the RPM setting, there will be $n/60$ rotations per second and ω will be $2\pi n/60$ radians per sec. Hence

$$\mu = v^2/rg = r\omega^2/g = r\,(2\pi n/60)^2/g = r\pi^2 n^2/\,900g.$$

You can repeat the procedure to find out the coefficient of static friction between striker material and all other discs. What would you do if you wanted to know the friction between, say, a polish paper (sandpaper) and copper clad?

You may also estimate the reduction in the value of μ when you use a dry lubricant like boric powder on the disc.

If you want to determine the coefficient of sliding (kinetic) friction, repeat the above procedure with a small but important change – every time start the turntable first and gently drop the striker at increasing radial distance until the striker slips away. Thus you will find that the critical distance is not the same as in

the earlier case. What is the conclusion?
The effect of sprinkling boric powder can also be checked in the case of kinetic friction.

Food for thought:

What is the direction of the force of friction in each case?

Does it provide centripetal force or centrifugal force?

Can we improve the accuracy of our measurements? How?

Can the same record player be used to study any other concept in physics?

Experiment 4. ***Study of Interference of Sound using Quinke's Tube***

Sound waves that are produced in a loudspeaker driven by a signal generator have (ideally) a constant frequency and intensity. If such waves are allowed to travel by two alternative paths to reach a common destination, the resultant intensity sensed at the destination will depend on the phase/path difference between the two components. If the paths differ by an integral multiple of λ, the wavelength associated with the waves, there will be constructive interference of sound waves traveling by two different paths and the intensity at the receiving end will be a maximum. On the other hand, if they differ by an odd integral multiple of $\lambda/2$, there will be destructive interference resulting in a minimum intensity of sound.

Referring to *Figure* 1, note that in the Quinke's tube, both the arms can be adjusted lengthwise and that if any one of them is

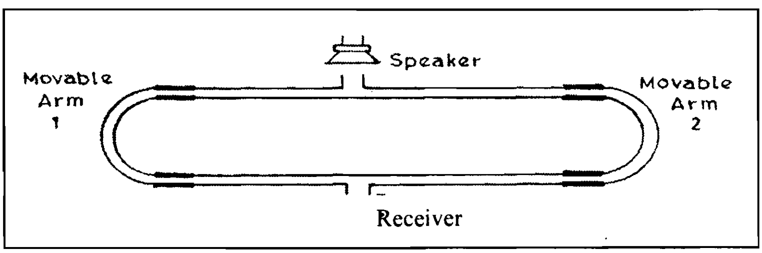

Figure 1. Quinke's tube setup for measurement of speed of sound in air.

pulled out by a distance x, the path increases by $2x$ since they are U-shaped. Thus, one can start with a minimum intensity position of sound at any suitable audio frequency, and move any of the arms through a distance x such that the next minimum intensity position is located. Under such a condition, $2x = l$. Knowing the frequency of the sound waves from the dial of the signal generator,' one can apply the formula $v = f\lambda = 2x\lambda$, where v is the speed of sound in air at room temperature, f is the frequency and x is the distance through which the arm has been moved in going from one minimum to the next in either direction.

The procedure is extremely simple. Repeat it for a large number of frequency settings starting from 300 Hz to 4000 Hz. Do you realize any difficulty in going beyond 4000 Hz? Work out the mean value of the speed of sound at room temperature and compare it with the standard value (330 m/s at 20°C).

Food for thought:

What are the factors governing the minimum and maximum frequencies of sound waves to get satisfactory results?

Can the method be applied to any other situation?

What modifications would be required to be made in such situations?

Can we improve upon the range of frequencies by making any alteration in the form of the tube?

Think about the probable sources of error.

Experiment 5. ***Transparency of Materials using a Photodiode and OPAMP***

Measuring the percentage transparency of different materials like glass, acrylic, etc. is an extremely useful yet a simple task by employing a linear photodetector like a photodiode and a low-cost electronic circuit employing general purpose OPAMP like IC 741.

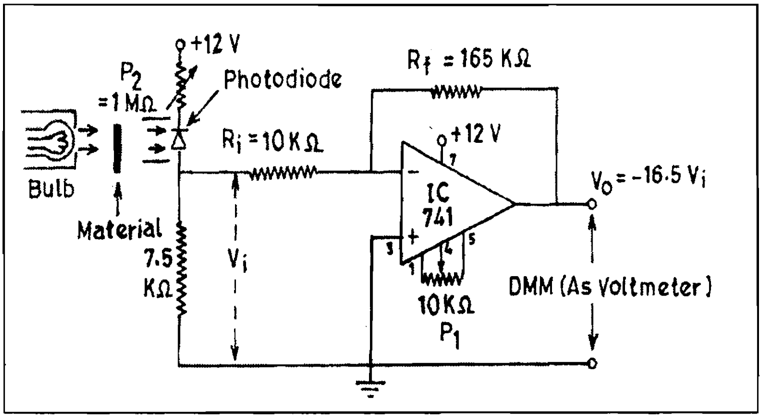

Figure 2. Circuit for measurement of transparency of materials.

The circuit is shown in *Figure* 2. A small bulb gives out almost white light that is channelised on a photodiode placed opposite to it at a distance of about a centimeter. The diode is suitably biased using a supply and a pair of resistors is connected in series with it such that the voltage across the fixed resistor (about 7.5 kW) is proportional to the intensity of light falling on the diode. The voltage is amplified by using the inverting amplifier combination of OPAMP 741 for which the gain is given by the ratio of the feedback resistor (165 k) to the input resistor (10 k). The amplified output voltage is measured using a digital multimeter (DMM).

The intensity of the light falling on the photodiode undergoes a change if any material in the form of a thin lamina is introduced in between the bulb and the photodiode. If all the light from the bulb is able to pass through the material, the material must be fully transparent (100%). On the other hand, if the material is opaque, there can be no light reaching the photodiode and the voltage read by the DMM should be set to zero. This is the basis of calibrating the instrument for which potentiometers P_1 and P_2 are used.

Food for thought:

How will you check the transparency of cellophane tape?

How does transparency of a material change with its thickness?