

Simple, Concept-Centred, Innovative, Open-Ended Experiments in Physics – 2

A W Joshi¹, V H Raybagkar² and
F I Surve²

¹Department of Physics
University of Pune
Pune 411 007, India.

²Department of Physics
Nowrosjee Wadia College
Pune 411 001, India.

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. This article describes briefly 5 more experiments¹ which we presented in the lab component. All the experiments are simple and do not require any sophisticated equipment. The article is based on the write-up distributed to the students.

Experiment 1. Study of an Electromagnetic Relay using an Oscilloscope

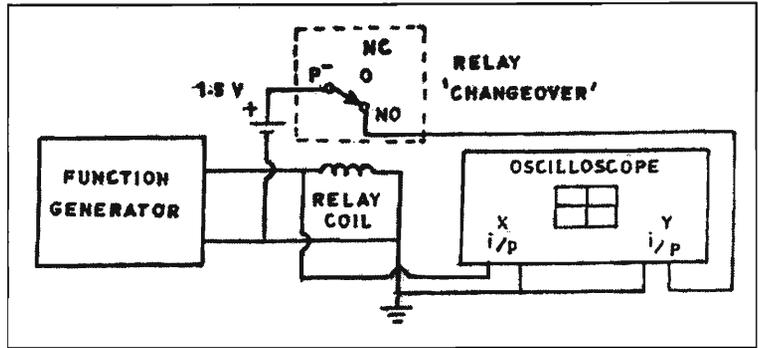
An electromagnetic relay is an important device in electrical engineering, power electronics as well as industrial instrumentation. It operates as an electrically controlled switch. Very often such devices are not supported by adequate specifications or performance parameters. It is therefore important to study their operation using certain simple procedures. They add to our understanding of the device so that we can make appropriate decisions and predict the performance of the circuit or system employing them.

In this experiment, you will employ the circuit shown in *Figure 1* to study a DC electromagnetic relay. The function generator produces a triangular or a saw-tooth waveform. When its voltage value (starting from zero) crosses the turn-on voltage, the relay switches on. Till this happens, you can watch only a spot moving from left to right along the *x*-axis on the oscilloscope screen. Just when the relay turns on, the spot moves vertically upward due to the voltage applied to *y*-input of the oscilloscope

¹Part 1. Simple, concept-centred, innovative open-ended experiments in physics, *Resonance*, Vol.8, No.7, pp.76-84, 2003

Keywords
Electromagnetic relay, diffraction, double refraction, potential well.

Figure 1. Set-up for the study of an electromagnetic relay.

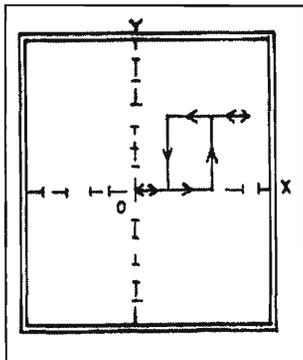


through the *changeover* of the relay. The spot then moves to the right until the applied triangular waveform reaches its maximum voltage.

Thereafter the voltage starts receding and the spot moves from right to left. It is interesting to note that the downward transition of the spot when the relay turn-off does not take place at the same position on the screen where an upward transition was seen. This is due to the *retentivity* of the core of the electromagnet that controls its switching action. One can adjust the frequency of the function generator so as to see the hysteresis loop on the oscilloscope screen as shown in *Figure 2*.

One can measure the turn-on voltage, turn-off voltage, turn-on (switching) time, turn-off, time and find the upper limit of frequency up to which such relays should be used in power control systems.

Figure 2. CRO display of the activity of an electromagnetic relay.



Food for thought:

Why should a triangular/saw-tooth wave be used instead of sine or square wave?

What would be the nature of the loop on the oscilloscope if a bipolar triangular waveform is used?

Can you estimate the energy dissipated in one cycle of magnetization of the core? If yes, what would you additionally need for it?

Experiment 2. Diffraction from Low-Cost 1-D and 2-D Gratings using a Laser

Transmission Grating: Low-cost 1-D and 2-D gratings can be made by using computer graphics, line draw, proper reduction, and final photocopy or print-out on a transparency, etc. If you have a 1200 DPI printer, you can directly take the print-out on the transparency. You can generate 100 gratings, 1-D and 2-D, with different line spacings, on an A4 size sheet. Thus you have 100 different gratings for less than Rs 50. Such gratings with grating element 35 to 47 lines/cm will be available. In spite of the large grating constant and low resolution, you can see a good diffraction pattern with the use of a laser because of the availability of large distances. Such gratings will not work with conventional spectrometer and sodium lamp. Students should determine the grating element in each case. The laser beam should be perpendicular to the grating as well as to the wall. Measure the distance between grating and wall (which could be 2 m to 5 m), and between the successive diffraction spots. Use the formula

$$n\lambda = d \sin \theta_n,$$

where d is the grating element, λ the wavelength of light used, n the order of diffraction and θ_n the angle of the n -th order diffracted ray from the zeroth order direct ray. See *Figure 3 a*. A piece of nylon cloth also serves as a 2-D grating. Determine the spacing between the fibers in a nylon scarf.

Reflection Grating: An ordinary steel scale serves as a diffraction grating in the reflection mode. But we need a laser beam for the experiment because diffraction spots are seen at fairly large

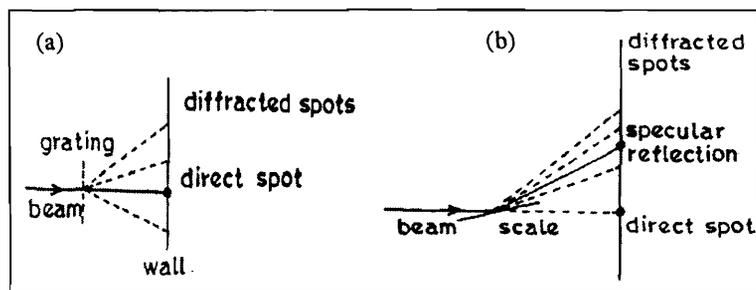


Figure 3. (a) Low-cost 1-D or 2-D transmission grating; (b) Diffraction from a steel scale.

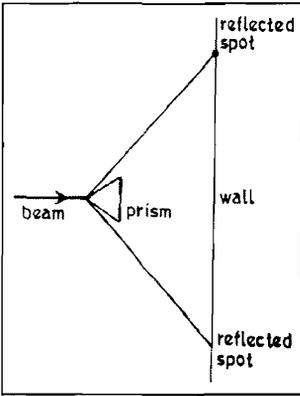


Figure 4. Measuring the angle of a prism.

distances of 3 m or so, which are not available with a spectrometer. Details can be found in [2].

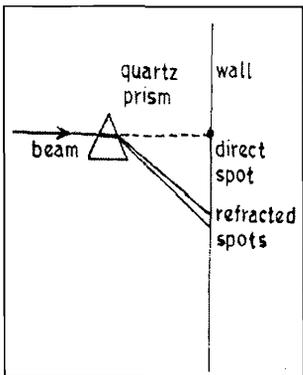
Double Refraction from Quartz Prism

Arrange the laser beam perpendicular to a wall. Insert a quartz prism in its path so that the beam falls on the edge of the prism. Adjust the prism to get two reflected spots, from the two faces, on the wall; see Figure 4. This will give you the angle of the prism. Now allow the beam to fall on one face of the prism and you will observe two refracted spots quite away from the original position of the spot, but close to each other. Arrange the prism for minimum deviation. Measure all the necessary distances and find both the angles of refraction. See Figure 5. Determine both the refractive indices using the standard formula

$$n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)},$$

where n is the refractive index, A the angle of the prism, and δ_m the angle of minimum deviation. Of course, you will have two values of δ_m and the corresponding refractive index n , one for the ordinary ray and one for the extraordinary ray.

Figure 5. Double refraction from a quartz prism.



In the case of quartz, the beam which suffers less refraction is called the *ordinary beam* and the other one the *extraordinary beam*. (There are other doubly refracting materials for which the extraordinary ray suffers less refraction than the ordinary ray.) The two refractive indices for quartz differ only by 0.01. Study the polarization of the two refracted rays with the help of a polaroid.

Experiment 3. Normal Modes of a Coupled Oscillator System

Two simple pendulums QA and RB, of equal length, are taken and they are hung from a string PS, at points Q and R, respectively. See Figure 6. PX and SY are two stands, and the distance

between them can be varied. The plane XPSY should be vertical. The end points of the string PS are fixed on the stands. The knots at Q and R are such that their positions, and hence the distance QR, can be varied. The lines PS and QR should be horizontal. Measure the following parameters: L , distance PS; d , distance QR; l , length QA = RB of the pendulums; s , sag between lines PS and QR.

The pendulums are allowed to oscillate so that QA and RB always remain in a plane perpendicular to the plane XPSY. This is a two-element coupled system. A normal mode of oscillations is that in which the phase difference between the two (or any pair of) elements remains constant, independent of time. This system has two normal modes, one with phase difference 0 and the other one with phase difference π . The first normal mode can be created by pulling both bobs together on one side and leaving them. The other normal mode can be created by pulling them on opposite sides of the vertical plane. Determine the time period and therefore the frequency of the two normal modes; call these frequencies ν_1 , ν_2 , respectively. You will find that while these frequencies depend mainly on l and s , their difference also depends on d . Study these frequencies by varying the parameters. Watch how the section QR oscillates in both the modes.

Then create the transfer mode, by holding one bob fixed and pulling the other one to one side, leaving both hands simultaneously. You will find that energy is transferred from one bob to the other and then back to the first one. After half the time period, the second bob momentarily comes to rest and the first bob gains the full amplitude, and after the full period, the first bob again momentarily comes to rest. Call this frequency ν_{12} . Can you see a simple relation between ν_1 , ν_2 and ν_{12} ?

Now do a simple calculation. If you had a single simple pendulum with frequency ν_1 , what would its length be? Does it match with the length l of the coupled pendulum? (It should not.) Why this difference? What does the length of the single pendulum correspond to? Both bobs A and B oscillate along arcs of circles

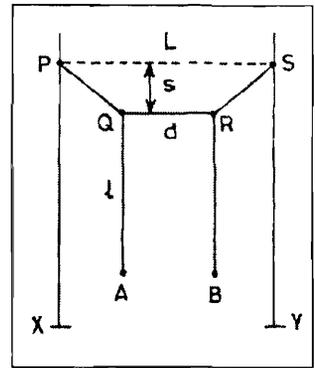


Figure 6. A system of two coupled simple pendulums.

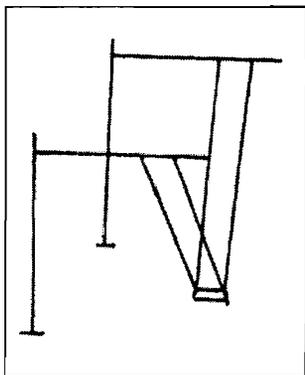


Figure 7. A bar hung with four threads, to enhance anharmonicity.

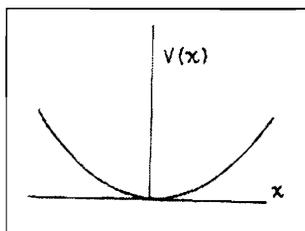


Figure 8. Schematic of potential in which the bar of Figure 7 oscillates. The potential may not be quite parabolic.

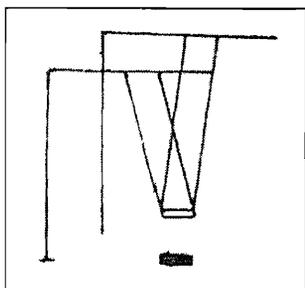


Figure 9. A magnet hung with four threads oscillating over another fixed magnet.

in a vertical plane. Where do the centres of these arcs lie? Can you figure out the correlation now?

Experiment 4. Study of Potential Wells and Hills of Different Shapes

Anharmonic Oscillations: A bar magnet is suspended with four threads, two at each of its ends, from two stands widely separated from each other. There is a hangman's noose at the upper end of each string which allows easy variation of length of each string. The stands and the strings are adjusted in such a manner that the bar magnet should lie in a horizontal plane when at rest, and should oscillate in the vertical plane containing the magnet. See Figure 7. This gives us an oscillator in which the anharmonicity (nonlinearity) is deliberately enhanced, for which the experimental characteristic is the variation of time period with amplitude. Study the time period and try to plot, qualitatively, the potential in which the magnet is oscillating. Figure 8 shows such a qualitative plot. The potential will deviate from the harmonic parabolic potential.

Potential Wells and Hills: Now place another magnet fixed on the table, under the oscillator, as shown in Figure 9. There are two simple ways when the two magnets are parallel to each other, *attractive mode* and *repulsive mode*, and of course many other ways such as tilted magnets, etc. Measure the time period for different amplitudes and try to plot qualitatively the profile of the potential in which the magnet is oscillating. You can construct (a) a deep potential well at the centre superposed on a shallow potential well, Figure 10 (a), (b) a potential hill between two potential wells, Figure 10 (b), (c) a potential hill between two asymmetric wells, and several such other one-dimensional potentials.

Whether you keep the fixed magnet on the table or not, and whether it is kept in attractive or repulsive mode, you will observe that the time period for large amplitude oscillations is the same in all the three cases. This suggests that the time period depends mainly on the shape of the potential curve at the end-

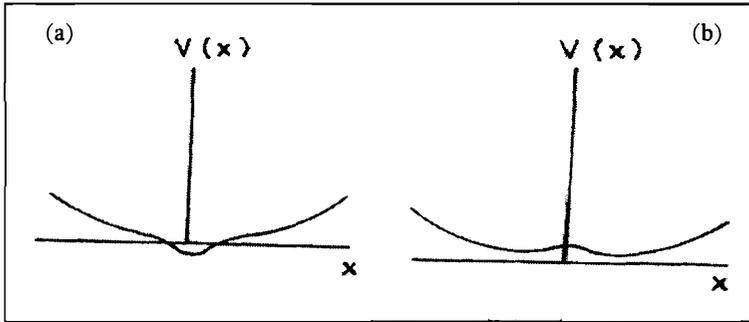


Figure 10. (a) A deeper potential well for small displacements superimposed on a shallower potential; (b) A potential hill between two potential wells.

points and not on what is there inside. This could be due to the fact the oscillator spends a large fraction of time near the endpoints.

For each section of the curve which is concave upward, we can approximate the small section of the potential curve around it as a parabola, $V(x) = 1/2 kx^2$. The value of k decides the shape of the parabola. A large value of k indicates a deep, sharp parabola, while a small value of k corresponds to a shallow parabola. This in turn is related to the time period T and the angular frequency ω through $\omega = 1/T$, and $\omega = \sqrt{k/m}$, where m is some mass. Here we disregard m altogether, because we want to plot the potential only qualitatively. The important point is that T is the observed parameter, at different values of x (different amplitudes), and then we use $T \propto \sqrt{1/k}$, or $k \propto 1/T^2$, to get the value of k for different x . In the case of a potential hill between two wells, whether symmetric or asymmetric, you will notice different time periods for large oscillations (energy above the top of the hill), and when the oscillations are confined to each potential well. This allows us to plot a qualitative profile of the potential. Notice that a small change in T produces a large change in the shape of the potential.

Suggested Reading

- [1] Umapati Pattar and A W Joshi, Head-on collision of two balls revisited, *Resonance*, Vol 7, No 6, p 67-77, June 2002.
- [2] A W Joshi, Umapati Pattar, and F I Surve, Diffraction from a steel scale in the reflection mode, *Resonance*, Vol.7, No.9, p.78, 2002.

