Visualizing Oscillations and Harmonic Motion an Educational Tool

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Abstract:

The concept of de Broglie waves is difficult to visualize at intermediate school levels for students. We designed an experiment to illustrate this in the laboratory using the concept of vibration of a metal ring in its own plane, under an alternating magnetic field. In this study we used a ring to visualize the transverse elastic vibrations formed when electromagnetic signal is applied. Same principle can be applied to the electron revolving in the orbit of an atom. Certain special orbits are possible for the electron only when its circumference is the integral multiple of the wavelength associated with the electron. The graphic visualisation is very useful in understanding how stable harmonics are formed and the wave like behaviour of an electron moving in the orbit.

Introduction

Students learn better and retain their knowledge longer when traditional classroom teaching is assisted by interactive experiments with visually depicted results in real time. Combined with traditional theoretical instruction and laboratory techniques, these methods provide new options to gain in-depth knowledge and understand the physical principles in the areas of physics under study [75]. We designed such an experiment using some very commonly available materials to illustrate the concept of harmonics and oscillation and draw an analogy to behaviour of an electron when in motion inside an atom. Such simple experiment could enable students to connect the learnings from the observations with different concepts by developing a mental framework and extrapolate this through thought experiments [2,3,4].

A well-designed, visually observable and easily replicable experiment can help provide clarity and d encourage students to connect their learning with theory and help memory retention of a concept and simple framework of understanding [5]. Group interaction and experimental observation will help students use the concept in different situations [1].

Principle of vibration in a ring:

Principle of vibration of a ring is based on the electromagnetic induction. Experimental setup is shown in the figure. A coil of thin wire is wound on a magnetic material. Ohmic resistance of this coil is about 1000 ohm. When alternating current is passed through the coil induced magnetic field is produced around it. This magnetic field is linked with the magnetic material, which induces the magnetization inside the magnetic material. When the strip of spring is kept in the vicinity of the magnetic material, alternating magnetic field is induced in the spring which induces an emf in the spring. This induced emf produces current through the spring. This induced alternating current again interacts with the magnetic field produced by the magnetic material in the coil and it vibrates according to lenze's law. As the spring vibrates with the applied frequency, standing wave patterns are observed for particular radius of circular spring. The number of the loops formed inside the circular spring depends upon the applied frequency and resonating length. It is given by the formula

$2\pi r = n\lambda$ Where r is the radius of circular spring

n is the applied frequency

λ is the wave length of the standing wave in the loop

This experiment illustrates a general technique which often helps us to discover the connection between two linked variables and hence the law relating them. This technique is commonly used in wide range of physical phenomenon and this study is the example of this approach which is often adopted by researchers to study new phenomenon.

The phenomenon chosen for investigation here is the vibration of a metal ring in its own plane. We commonly notice that if a steel hoop is bounced it culvers or vibrates at the some definite frequency. It gives out a ringing sound, as does a straight steel bar. These are relatively simple cases, but the percussion player's triangle gives out a variety of high pitched notes dependent on just how and where it has been struck.

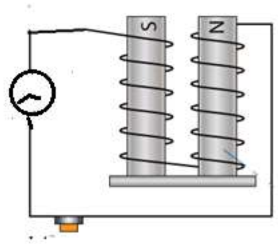

Figure 1: Driver electromagnet from telephonic ear piece

As with all natural oscillations, two factors seem to control the frequency of vibrations i.e. the pitch of the note emitted – a factor easily verified if it lies within the audible range. The factors which also determine the velocity of a wave traveling through the material are:

(a) A mass or inertial quality possessed by the body

(b) A quality of springiness or elasticity

As might be expected, increase of the mass reduces the frequency while increase of elasticity increases the frequency. In most cases the vibrations of a struck body die out quite rapidly because of damping factors such as air viscosity - the energy dissipated as a sound wave is absorbed. In order to maintain the size of vibrations fresh energy has to be injected in to the body. When this is done by the pulses applied at just the right instant, the oscillations becomes continuous and the body resonates. Resonance is an important mechanical phenomenon, but even more important is its electrical counterpart since this underlies the generation and reception of audio waves.

Our experiment requires an audio frequency oscillator, power supply, telephone ringer, transistor, and resistance. The special ring vibrator for this experiment has been constructed. The desired features are:

(a) Adjustable radius.

(b) Uniform and circular.

(c) Free but not too violent movement in resonance

(d) Purely radial vibration of antinodes, the points of maximum displacement.

These requirements cab be easily modelled and the best material for the ring proved to be a clock spring about 50 cm long and 0.5 cm wide. This spring can be easily straightened by pulling it over a sharply rounded edge. This spring was made into a circular loop by clamping its two ends to give it a circular shape, which can be varied as required in the course of the experiment. The length of the strip is marked in cm. A discarded telephonic ear piece of 1000 ohm resistance is used as a driver electromagnet. The ear piece was firmly screwed down on a block of wood after the original telephone diaphragm and its holding ring was removed. The width of spring is 5mm it fits well in the gap which is 6mm between pole pieces. The spring was clamped 1mm above the poles. When the length of the spring is altered its height above the poles tend to vary, so it should be adjusted with the help of a rocking block, which can be adjusted and clamped with the sleeve and clamping screw.

Procedure:

Set the spring at the required length and vary the frequency of the audio oscillator. Observe the ring carefully against the white background. At a definite frequency it develops nodes and anti-nodes just as the vibrating string develops in the Mede's experiment. The number of loops in case of a ring is same as number of stationary nodes. The number of loops increases as the frequency increases. We get a definite number of loops at definite frequency at resonance. Careful adjustment of frequency produces large vibrations at resonance. It sometimes induces a violent axial wobble in the string. The antinodes usually form beyond the energizing poles, though their precise position does not appear to influence the system of vibrations appreciably.

A violin string usually vibrates as a whole giving its fundamental note but the violinist may also play harmonics. This he does by lightly touching the string at some exact point, a node, in order to produce a high overtone of the fundamental note. If very lightly touched at the centre, for example, the string sounds its octave harmonic and vibrates in two loops or partials but a whole series of notes or harmonics result from inducing the nodes at the other positions. Similarly in case of our ring vibrator, the number of loops depends upon the frequency of signal generator and the radius of the circular loop.

We can select the number of loops to be induced, while we increase the length of the coil in the steps of, say, 1cm. The frequency 'ν' in Hertz set for this mode of resonance for length 'l' cm are tabulated below in Figure 2 . It has been observed that for steady vibration, the frequency required for resonance is proportional to the radius of the ring. The graph of l vs ν is part of curve, as shown in Figure 3. This has inverse proportionality since, we have

$$\text{Length}, \ l = 2\pi r = n\lambda \ \text{or} \ 2\pi/\nu.$$

Thus, length l is inversely proportional to frequency, ν

l (cm)	ν (Hz)	log l	log ν
20	375	1.301	2.57
25	230	1.398	2.36
30	160	1.477	2.2
35	120	1.544	2.08
40	90	1.602	1.95

Figure 2

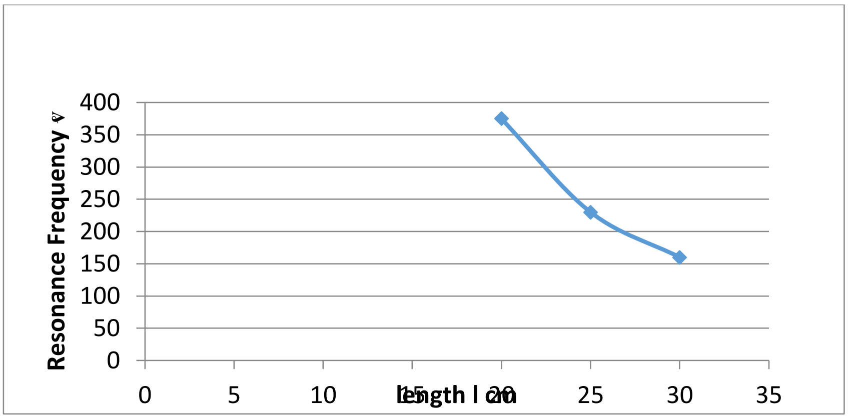

Figure 3

Thus, we have log l and log ʋ as a straight line with constant negative scope for any given setup of radius of the coil.

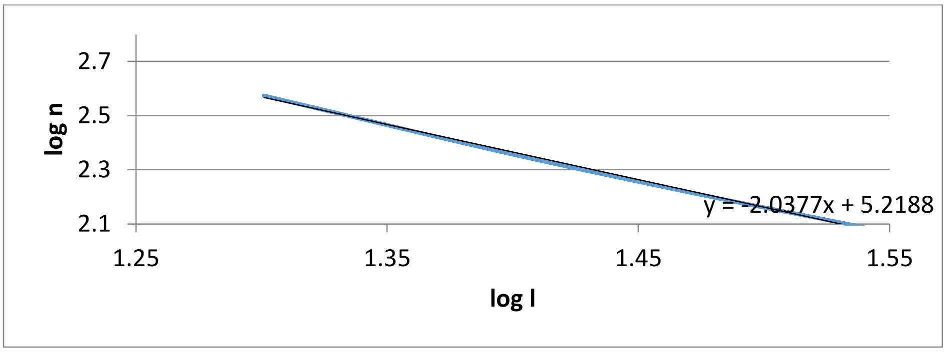

Figure 4

Thus, it is clear that the number of loops formed depend on then frequency and length of the string (i.e. the radius of the circle. As we vary the frequency of the current, we can observe the dampening effect when the condition Length , l= 2πr = nλ or 2π/ ʋ is violated i.e. the col loop does not contain full wavelengths.

Also, if we change the material of the wire, the number of loops changes illustrating that the harmonics depend on the density of wire material.

Conclusion

The experiment conclusively demonstrates how standing waves are formed and the various factors that can influence their behaviour. The concept that full wavelengths between two nodal points are required for a sustained harmonic motion is central to wave theory and is illustrated very graphically in the study. The fact that if this condition in not met then the waves damp out is central to concept of interference. The concept of harmonics and their extension to wave nature of electron can be explained to students very visually using this experiment.

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