Resonance Lab

This lab is intended to help you understand:

1) that many systems have natural frequencies or resonant frequencies
2) that by changing the system one can change its natural frequency
3) that systems oscillate the most when driven at this natural frequency
4) that this is true for mechanical and electrical systems and is how radios are tuned

Introduction:
What does it mean when someone says, “That idea resonates with me.”? In the natural world many things have a preferred rates at which they will oscillate or a “resonant frequency”. Some natural fundamental frequencies are very obvious, for example that of a tuning fork. This is not surprising as tuning forks are designed to vibrate or oscillate at a particular frequency so as to produce a specific note (e.g. 440Hz). Swing sets also have a natural rhythm. If you want to make the swing go high you need to match the rate at which the swing tends to move back and forth.

Other natural frequencies may be less apparent such as that of a building, which determines if it will or will not fall down during an earthquake, or the rate at which an electron moves from one orbital in an atom to another. In the laboratory there are many ways that we take advantage of natural frequencies of objects. These rhythms can tell us about the physical characteristics of an object. More importantly for astronomy, they are the only way that we can probe distant objects that we can never hope to visit. For example on earth we can detect radio signals from pulsars, which are rapidly rotating neutron stars many light years away; and even radio waves that are from the infancy of the universe, billions of years ago. This ancient light is called the cosmic microwave background and many scientists at the Center for Cosmological Physics are currently studying it to learn about the early universe.

We can detect radio signals from distant radio stations and even astronomical sources, because radio waves are electromagnetic waves that can move electrons back and forth in our antennas, which then move electrons in our detectors a.k.a. radios. In this lab we will examine how a number of mechanical systems oscillate or move back and forth, and how one electrical system oscillates; and we will explore resonance in these different systems.

Ask yourself:

What influences the amplitude or size of the vibration?
Can something have more than one resonance or natural frequency?
How can you change the natural frequency of a system?
Resonant Rings

One reason not all buildings are equal in an earthquake.

This device graphically demonstrates that objects of different sizes and stiffnesses tend to vibrate at different frequencies.

**materials**

- A sheet of cardboard measuring 1 foot (30 cm) long and several inches wide.
- A large sheet of construction paper (about 14 x 20 inches [35 x 50 cm]).
- Masking tape or transparent tape.
- Plastic drinking straw
- BB’s
- Scissors

**assembly**

(15 minutes or less)

Cut four or five 1 inch (2.5 cm) wide strips from the construction paper. The longest strip should be about 20 inches (50 cm) long, and each successive strip should be about 3
inches (8 cm) shorter than the previous one. Form the strips into rings by taping the two ends of each strip together. Then tape the rings to the cardboard sheet as shown in the picture.

Cut a 1 inch (2.5 cm) section of plastic drinking straw, insert a BB into it, tape paper over the ends of the straw, and tape the straw to the cardboard sheet parallel to the short end of the cardboard.

to do and notice

(5 minutes or more)

Shake the cardboard sheet back and forth. Start at very low frequencies and slowly increase the frequency of your shaking.

Notice that different rings vibrate strongly, or resonate, at different frequencies. Record your observations of how the rings wobble in your lab notebook. Which ring vibrates strongly first? Which one last?

Keep shaking the cardboard faster and faster, and notice that the largest ring will begin to vibrate strongly again. Each ring will vibrate at more than one frequency, but the shape of each ring will be different for each resonant frequency.

Investigate the resonant frequencies of the rings if you shake the board up and down instead of sideways. Record your observations in your lab notebook.

what's going on?

The frequencies at which each ring vibrates most easily (its resonant frequencies) most easily are determined by several factors, including the ring's inertia (mass) and stiffness. Stiffer objects have higher resonant frequencies, whereas more massive ones have lower frequencies.

The biggest ring has the largest mass and the least stiffness, so it has the lowest resonant frequency. Put another way, the largest ring takes more time than the smaller rings to respond to an accelerating force.

During earthquakes, two buildings of different sizes may respond very differently to the earth's vibrations, depending on how well each building's resonant frequencies match the "forcing" frequencies of the earthquake. Of course, a building's stiffness - which is determined by the manner of construction and the materials used - is just as important as a building's size.
Part II. Wobble Sticks Resonator  (adapted from Exploratorium Snacks
www.exploratorium.edu/snacks/resonator.html)

The wobble stick resonator consists of a number of wooden dowels of varying lengths with identical masses, in this case superballs, attached to their ends. The dowels are attached to the same board so that all will be shaken the same way.

**to do and notice**

(15 minutes or more)

Grip the 2 x 4 inch board at each end and slide it back and forth across a tabletop, moving it lengthwise. As you vary the rate of shaking, different dowels will swing back and forth with greater or lesser amplitude. When you are shaking at just the right frequency to cause one dowel to vibrate violently, another dowel may hardly be vibrating at all.

Notice which dowels vibrate violently at lower frequencies and which vibrate violently at higher frequencies. **(CAUTION: If you get the dowels vibrating too violently - watch out! - they may break!)**  Record your observations in your lab notebook. Which dowels vibrate first? Last?

**what's going on?**

When you push a person on a swing, a series of small pushes makes the person swing through a large amplitude. To accomplish this, you time your pushes to match the swing's natural frequency, the rate at which the swing tends to move back and forth.

The same principle is at work in this Snack. When you shake the 2 x 4 assembly at just the right frequency, a series of small shakes adds up to a large vibration of a particular dowel. The shaking board sets the dowel vibrating. If the next shake is timed just right to reinforce the next vibration of the dowel, the vibration in the dowel builds up. This process of using a series of small inputs to create a large motion is known as *resonance*.

Each dowel may have more than one resonant frequency.
Part III: Pendulums

What’s My Frequency? *Determine the natural frequency of your pendulum.*

**Materials:**
Sting, mass, clamp, stopwatches, ring-stand

**Step 1:** Working in pairs, build a pendulum. In your lab notebook, sketch your pendulum. Include a measurement of the length of the string and note the mass of the bob.

**Step 2:** Swing your pendulum. Start the pendulum, by pulling it back about 25-30 degrees from where it hangs at rest. Experiment with this until you are able to make it swing back and forth in a nice smooth regular fashion. Be sure that it only swings from side-to-side and not back and forth. Now you are ready to determine it's natural frequency.

**Step 3:** Time your pendulum. To do this we will measure the period of one full swing or cycle. A full cycle means that the pendulum has traveled through all the parts of its swing and is back where it started.

If you start it 25 degrees to the right a full cycle means swinging down to the bottom, up to the left, back down to the bottom and finally back up to the right. The amount of time that it takes to complete one full cycle is call the period (T). The period, or amount of time per cycle, is directly related to the frequency.

**Frequency** (*f*) is a term that means how many cycles per second. The unit for frequency (*f*) is **Hertz** (*Hz*) 1 Hz = 1 cycle/second. If you can measure the period (seconds/cycle), it is easy to calculate the frequency (cycles/second) as it is just the inverse of the period \( f = \frac{1}{T} \). *Why do you think we are measuring T to find f rather than measuring f directly?*

1) In your lab notebook guess or estimate how long the period of your pendulum is.
2) Construct a table in your lab note book
3) Since the pendulum swings fast we will measure how long 10 cycles takes rather than one to determine the period. We will average ten complete cycles. You may notice that the amplitude of the swing decreases after awhile. This is because there is friction and air resistance in our system that will eventually dissipate some of the initial energy. For example if it takes 20 seconds for 10 cycles then:

\[
T = \frac{20 \text{ seconds}}{10 \text{ cycles}} = 2 \text{ seconds/cycle},
\]

and \( f = \frac{1}{T} = \frac{1}{2} \text{ cycle/second} = \frac{1}{2} \text{ Hz}. \)

**Step 4: Do all pendulums swing the same?**  
Compare all the different groups’ pendulums. Which one is the fastest (i.e., has the highest frequency or shortest period)? Which one is slowest? What do you think influences if a pendulum is fast or slow? Test your predictions. Record your predictions and how you tested them in your lab notebook.

**BIG Swinger!**  
We are now going to investigate really big pendulums. How they like to swing and how you can make them swing.

Adapted from [http://www.exploratorium.edu/snacks/resonant_pendulum.html](http://www.exploratorium.edu/snacks/resonant_pendulum.html)

**Resonant Pendulum**

Big swings from little pulls grow.
By exerting very small forces at just the right times, you can make a massive pendulum swing back and forth in very large swings.

**to do and notice**

As a group we will assemble a jumbo pendulum that uses a paint can filled with sand as a bob. The can should hang somewhere between waist height and ground level. The closer to the ground it hangs, the less traumatic the results if it should somehow fall. Stand a few feet away and throw the magnet at the can. Your goal is to get the magnet to stick to the can. Once you have done this, pull gently on the string to set the can in motion. If you pull too hard and the magnet pulls off, try again. By pulling very gently on the string, but only pulling when the pendulum is moving toward you, you can gradually make the pendulum swing in very large swings. Time the swing of the giant pendulum and estimate its period. *How does it compare to you tabletop pendulum? Why do you think they are different? How would you test your prediction?*

**what's going on?**

A very small force, when applied repeatedly at just the right time, can induce a very large motion. This process is known as resonance. Perhaps the most familiar example of resonance in everyday life is swinging on a playground swing. The first push or pump sets the swing in motion. Each subsequent push or pump is delivered at just the right time to increase the amplitude of swing. If you continue pushing or pumping over a period of time, the swing will gradually go higher and higher.

Every pendulum, from a playground swing to your hanging paint can, has a *frequency* at which it tends to swing. This is the pendulum's *natural frequency*. To find the natural frequency of a pendulum, just pull it to the side and release it. The pendulum will swing back and forth at its natural frequency. If the frequency of pushes on a pendulum is close to the pendulum's natural frequency, the motion and the pushes will remain in step. Each successive push will increase the amplitude of the motion of the object.

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Part IV Forced Oscillations:

In the part of the lab we will investigate more carefully what happens when you shake something at just the right rate. Recall that both the paper rings and the big pendulum moved much more at some rates than others. The technical term for when the rate of pushing just matches the natural frequency of the system is **resonance**.

![Diagram of a motor pushing an oscillator on an air track with springs.](image)

Our first investigation into resonance will involve a simple mechanical system that has a fairly fancy looking setup. The system allows us to push the oscillator at different rates. The system is a weight and two springs on an air track with a motor on one end to push it. If you stretch a spring it wants to move back to where it was before, if you compress a spring it will push back, but in the opposite direction compared to when it was stretched, similar to how a pendulum swings. When moved, or in technical terms displaced from equilibrium, the mass on the spring will overshoot the rest point and start an oscillation. If you had a perfect spring and a world without friction this would continue infinitely. Our system is fancy and includes an air track to make the physics simpler, i.e., less friction. However, the basic idea is simple: the motor can drive the oscillator (springs and weight) at different rates by pulling on the sting.

**Driving Miss Daisy:** As a group we will see what happens when we change the rate that we are driving the oscillator. We will change the frequency of the motor and measure how far the car moves from its rest position. The technical term for this change is displacement from equilibrium. We will incrementally increase the motor speed. After each change we will have to wait for the system to settle down and get used to the change, and finally measure the size of its swing.

**In your lab notebook**

- Predict what will happen as the motor frequency is increased. Explain.
- Record each motor setting, and the associated displacement from equilibrium i.e., the amplitude of the swing.
- Graph frequency (motor setting) vs. amplitude if possible.
- Compare your prediction to the measured results.
Driving Miss Electronic Daisy - Or How to Tune a Radio: Have you ever wondered how an AM radio is able to select among the many stations that are broadcasting at any given time? Or why the thousands of other radio sources both natural and man made can be tuned out? The answer is resonance. You may remember from when you built your own crystal radio or from the other labs in the institute that a tuner essentially consists of a capacitor and an inductor. Together they form an electronic oscillator. The resonant frequency of the oscillator can be changed by either changing the capacitor (as you did with your crystal radios) or by changing the inductor. By changing the frequency of the circuit one selects a radio signal that is being broadcast at matching frequency.

The electronic oscillator is similar to the mechanical oscillators that we have been working with. Capacitors you may recall store energy in the form of electric fields while inductors store energy in magnetic fields.

![Diagram of an electronic oscillator with a capacitor and an inductor.](image)

We can see how the circuit will oscillate if we imagine first charging the capacitor with a battery and then placing the inductor into the circuit. The capacitor will begin to discharge through the inductor. As this happens the inductor will create a magnetic field. Once the capacitor is completely discharged the magnetic field of the inductor will try to keep the current moving and so it will recharge the capacitor but in the opposite way that it was charged before. Once the inductor’s magnetic field collapses, the capacitor will be recharged with the opposite polarity and ready to start the whole cycle in reverse. In a world without resistance this cycle would just continue. In order for a radio station transmitter to drive this circuit is must be resonant with the natural frequency of the capacitor inductor pair. Compare this to the driven mechanical oscillator in this case the driver is the radio transmitter.

In this lab we will quantitatively measure how resonance affects the amplitude of the signal received.
**Materials:**
Sensitive Digital Radio Receiver  
Radio Transmitter (1000KHz or other known frequency)  
Radio, Tape Player or other source of music  
Digital Multimeter  
Antenna

**To Do:**

As there is only one assembly the lab instructors will set it up. The assembly consists of a transmitter and a receiver. The transmitter will be connected to a source of music that it will broadcast (e.g., a cd player or a household radio) on an uncluttered frequency of the radio spectrum. The receiver is much fancier than a normal household radio. It is a Ham receiver that allows us to tune it very very precisely. A typical ham receiver’s range is from 1000KHz to 30MHz. Connected to the receiver will be a digital multimeter that will measure the receiver’s output. The multimeter will measure voltage and can be considered the same as amplitude of the strength of the signal received.

**Testing, Testing, 1, 2, 3…**  
First confirm that the transmitter receiver combination work at the assigned frequency. Transmit some music and confirm that you can hear it on the receiver.

**Detune the Signal & Measure the Output:**  
Once you have confirmed that the broadcast signal is working, detune the receiver by 20KHz (i.e., if the transmitter is broadcasting at 1000KHz, tune in at 980 KHz). In your lab notebook in a data table, record the output voltage measured with the multimeter. Measure the output voltage 3 times for each frequency, record and average the measurements. Repeat these measurements, increasing the receiver frequency by 5 KHz each time until you are 20 KHz above the broadcast frequency.
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<tr>
<th>Frequency (KHz)</th>
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<th>Voltage trial 3 (milivolts)</th>
<th>Average Voltage (mV)</th>
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**Graph** your measurements in your lab notebook. Place Frequency on the x-axis and amplitude (voltage) on the y-axis.

*When was the amplitude the greatest?*

*What factors do you think affect the strength of the received signal?*

*Why do you think you were asked to average 3 measurements?*

The third definition for resonance in the *American Heritage Dictionary of the English Language 3rd Edition* is "*Physics. The increase in amplitude of an oscillation of an electric or mechanical system exposed to a periodic force whose force is equal or very close to the natural undamped frequency of the system*"