Tu. 3/5: Ch 16 *Sound Reproduction* **Th. 3/7:** Ch 16 *Sound Reproduction*	HW7:Ch16:1^W,7^W,11^W… Ch16:13^W,18^W,19^W	**Mon. 3/3** or **Tues. 3/4:** Lab 8 *Percussion pt 1 - Drums*

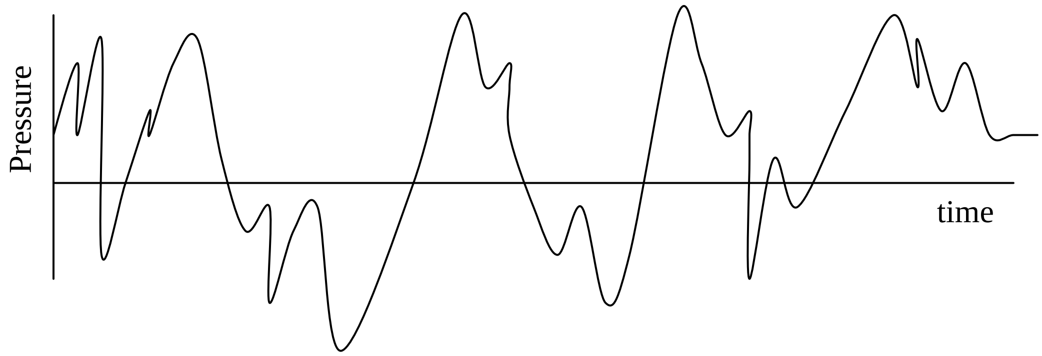
Administration: No lab this week (delaying the Natural Modes lab until after Patrick's presentation on a type of drum).

Equipment: (takes over an hour to get it all rounded up and set up)

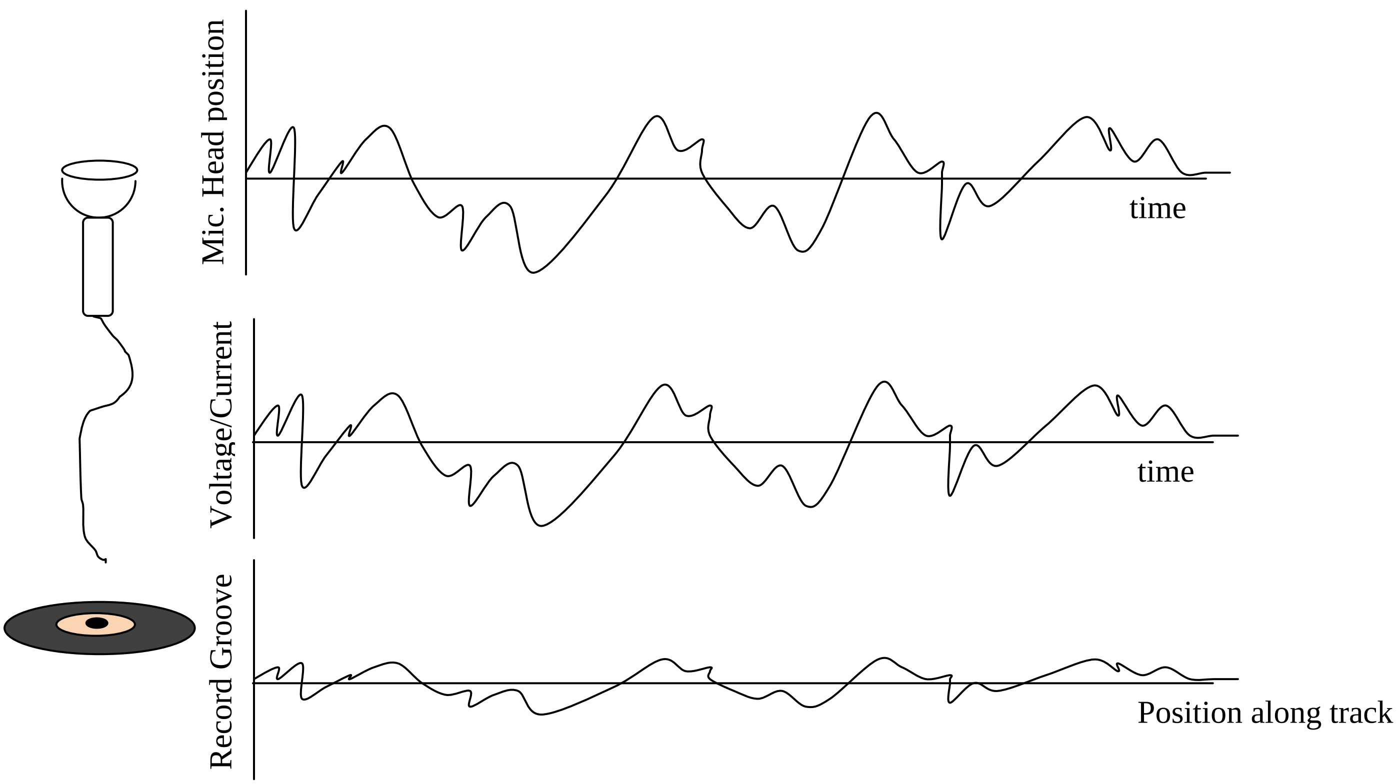
- **PhET Circuit Simulation**
- **Electro statics –** pith ball, rod and rabbit fur.
- **O'scope (with USB control)**
    - **Laptop with O'scope program, USB cable**
- **Electronics' ppt slides with piezo illustration**
- **Electrometers & wire**
- **Battery**
- **Van der Graff generator**
- **D battery, resistor, galvanometer (and ways to connect, perhaps clips and battery holder)**
- **Parallel and anti-parallel currents attracting and repelling demo – board, wires, clips, and supply.**
- **Magnet**
- **Little RCA stereo amps, ipod, and male-male cable to connect.**
- **Speaker, and cables to plug into O'scope**
- **O'scope (and LabView's program for watching signal)**
- **Microphone (that I don't care much about) and cables to plug into function generator**
- **Capacitor plate base, sheet of paper, and sheet of aluminum foil. Clips to connect to function generator, maybe tape to hold it together at the edges. Probably need a battery between the capacitor and ground?**
- **Open Piezo buzzer & function generator; does wiring to o'scope register when compressed?**
- **Variable separation capacitor plates & voltmeter**
- **Current swing and magnet**
- **Foil, clip, resistor, paper and magnet – function generator drive current through foil**
- **Dixie cup speaker**
- **Ball-spring models of solid and wire**

Chapter 16 Sound Reproduction

Introduction Say a sound is produced. At some point in space, say the pressure varies as shown in this plot.



But how do I know that that's the exact pattern? How can I hope to pluck this pattern from the air and set it down with pencil on paper? Or chalk on board, or *any* recording medium? Only in the last century or so have devices been developed that can do just that. Furthermore, we have devices that translate the pattern *back into air pressure – sound waves*. In general terms, the pattern of air pressure variations through time is a signal or information. Today we will talk about devices that sense this information and translate it into another medium, an electrical medium; devices that take the newly electrical information and transcribe it – write it down, on magnetic tape or a CD; devices that read back and again produce electrical signals; and finally devices that translate these electrical signals back into the medium of the air – back into sound.



And back again to a current/voltage, motion of a *speaker's* head, and finally variations in pressure – sound.

These next two days we'll focus on how this translation back and forth works and, with that knowledge, we'll identify tradeoffs and imperfections – why music over your stereo is identifiably not live.

16.1 Electric and Magnetic Concepts

- Since these devices strongly rely on electric and magnetic interactions, we need to first develop some of the E & M vocabulary.

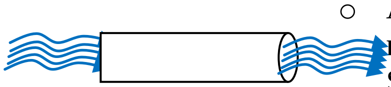
16.1.1 Charge

- **Atoms**
  - The vast majority of mater around us is built of atoms; atoms are built of three fundamental particles: Neutrons, Protons, and Electrons. They combine in something of a miniature solar system, with the neutrons and protons sitting together as the sun and the electrons more or less orbiting them like the planets.
- **Charge**
  - Along with the fundamental property of mass, the protons and electrons have another property called charge. Charge comes in two flavors, for simplicity called + and -. It so happens that electrons have one flavor, - , and protons have the other, +.
- **Electric Interaction**
  - Particles of like charge repel each other and particles of opposite charge attract. For this reason, atoms typically have the exact same number of electrons and protons – the attraction of the electrons for the protons is just balanced by their repulsion from each other.
  - The interaction gets stronger as the charged particles get closer.

Demo: Charge pith ball & then approach with charged rubber rod.

16.1.2 Current

- **Conductors**
  - As I said, all matter is built up of these atoms. For some materials, like copper, aluminum, etc. the outer most electrons are pretty mobile. These are known as conductors.
- **Water Analogy**
  - A wire of such material is like a pipe full of water; you pump in a little more water on the left end, and water flows out of the right end. Similarly, if you pump electrons into the left end of a wire electrons flow out the right end.

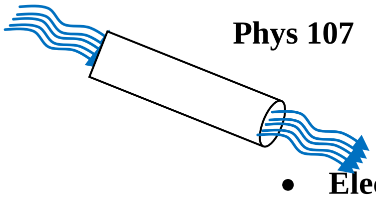


- **Current**
  - Just as you could call the motion of the water through a pipe a water current, we call the motion of electrons, an electrical current.

Demo: **Charge up one electrometer, then use wire to transfer charge to another.**

16.1.3 Voltage

- **Water, Elevation, and Pumps**

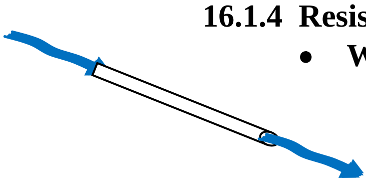


- Water in a pipe naturally flows down hill, from high elevation to low elevation, or can be made to flow up hill by a pump.

- **Electrons, Voltage, and Mechanical drives**
  - Similarly, electrons in a wire naturally flow from an over abundance of electrons (net – charge) to a lack of electrons (net + charge), but through chemical or mechanical processes can be forced back "up hill", cramming more and more electrons in together.
  - Analogous to the difference in elevation that drives the flow of water, we say there is a difference in **Voltage** that drives the flow of electrons.
  - If two ends of a wire have a big voltage difference, the current flows very rapidly down hill; if two ends have a small voltage difference, the current flows slowly. If the voltage difference seesaws back and forth, then the current oscillates back and forth.
  -

Demo: battery to charge up electrometer
Demo: Vann der Gaff generator

16.1.4 Resistance



- **Water, Rocks**
  - Now water would flow pretty quickly down a wide, un-obstructed pipe. But say you join a fat pipe to a stretch of narrow pipe, and worse yet, you fill the narrow pipe with rocks. This severely limits the flow of water.
- **Electricity, Resistance**
  - Similarly, too thin and imperfect wires or other materials limit the flow of current through a circuit. We call this limiting property their **Resistance.** There is an interplay between voltage – driving the current to 'run down hill' and resistance slowing the currents progress.

Demo: D battery shorted through an old fashioned galvometer, then conntected through a resistor and galvometer.

16.1.5 Magnet

- **Neutral wires**
  - Now, it's important to understand that, just because current is flowing through the wires, the wires needn't have a net charge. When a current flows, there aren't *more* charged particles on the wire, it's just that some of them happen to be moving. Similarly, when water flows through a pipe, there isn't *more* water in the pipe than when it's sitting stationary, it just happens to be moving.

- **Current and Magnetic interaction**
  - **Relativistic perspective**. Take two conductors side by side, we'd see them as carrying current but being charge neutral. *However*, if you were to put yourself in the shoes of one of the electrons moving along the wire, and you looked over at the other wire, you'd see things a little differently. If the electrons flowing in the other wire moved alongside you, then the atoms in the wire would appear to be *more densely packed than the*

electrons, making the wire look positively charged, and thus attractive. Or if the current in the other wire had the electrons flowing against you, you'd see those electron's more densely packed still, so the wire would be repulsive. This should sound *crazy*. And yet…

Demo: Parallel & Anti-Parallel wires

- It really happens. That lengths look different if you're in motion (as the electrons are) is a Special Relativistic effect. We call this particular effect **magnetism.**
- A "permanent magnet" is an object that has a perpetual loop of current flowing inside of it - the electrons about their individual atoms spin the same way.

Demo: Single wire and a magnet held parallel and anti - parallel

16.2 Transducers

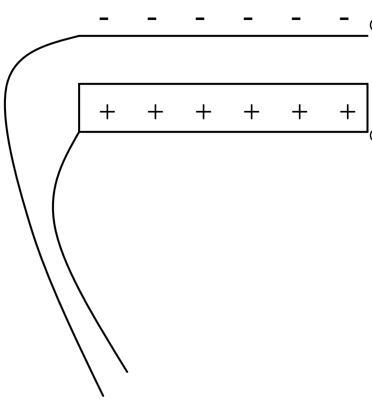
- With that under our belts, we are ready to talk about devices that use these properties and interactions. First we'll consider those that *translate* a time varying pattern of pressure in the air into the same time varying pattern of current or voltage in a conductor. These devices go by the general name of **Transducers.**
- **Microphones** translate waves in air into waves in electricity.
- **Speakers** translate waves in electricity into waves in air.
- We will go through some basic styles of transducers, and thanks to reciprocity, when we understand how, say an electro-static speaker works, we'll also understand how an electro-static microphone works.
- **Reciprocity**
  - **Language Translation Reciprocity**
    - Running with the *translation* theme; if a person has got all the necessary skills and tools to translate a passage from French into English, then wouldn't you expect them to also be able to translate a passage from English into French? Now maybe their tools are optimized for running the translation one way rather than the other, say they have a French -> English dictionary, but not an English -> French one, still they *could* translate back.
  - **Sound / Electrical Transduction Reciprocity**
    - The same can be said of transducers. If one can take the input of a sound wave and translate it into the output of an electric wave, then by running in reverse, it could take the input of an electric wave and translate it into an output of a sound wave. We call this reversibility **Reciprocity**.
    - So a microphone run back wards can be a speaker and a speaker run backwards can be a microphone.
- **Demo: Plug a microphone into an amp as a speaker & drive with a function generator.**
- **Demo: Plug a speaker into an oscilloscope and push the speaker head.**
    - As you've seen, they both *can* do each others jobs, though they've been optimized to do their own - the speaker has been optimized to work with big pushes of air, so when I feed it little pushes of air,

it has a hard time. The microphone is optimized for working with little pushes of air, so when I ask of it big pushes, it has a hard time.

16.2.1.1 Electrostatic / Condenser / Capacitor

Demo: Put aluminum foil on top of a piece of paper on a capacitor plate, then wire the sheet and the plate to a function generator.

- **Underlying Electronics Rules**
  - Like charges repel and opposite charges attract
  - a power supply can be used to "pump" many like charges together.



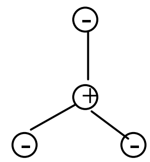
- **Construction**
  - Say we had a metal plate and a metal foil suspended, taunt, just above it. Wires run from the two.
- **Operation As Speaker**
  - We drive a current of electrons onto the foil and off of the plate. The excess electrons don't like being crammed onto the foil, but they feel an attraction to the + charge revealed on the plate. Trying to get to the + charges, they *drag* the foil with them toward the plate. But the foil is taunt, so it only bends so far.
  - Now reduce the charge on the foil; the foil relaxes away from the plate. Increase the charge on the foil; it bends in toward the plate. Do this over and over, and the foil flexes in and out. As it does so, it pushes the air over and over.
  - This produces a sound wave mimicking the varying electrical charge on the foil.
- **Operation as Microphone**
  - Say the plates are charged up + on one and – on the other.
  - When the air pushes the foil closer to the plate, it is easier for – charged electrons to be on the plate, so a few more come on, thanks to the attraction to the near by + charges on the plate.
  - When the air releases, the foil flexes back out. Now that the – electrons on the foil and excess + protons on the plate are further apart, their attraction is weaker, it's harder for the electrons to be crowded together on the foil, so some leak off into the wire.
  - The air pushes, the foil approaches the plate & electrons flow on, the air releases, the foil leaves the plate and electrons flow off. The current of electrons flowing mimics the variations in air pressure on the foil.

Demo: charge up two capacitor plates with a battery, then bring them closer and farther while connected to volt meter

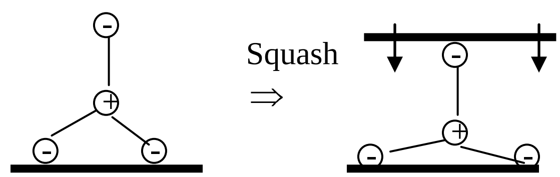
16.2.1.2 Piezoelectric / Crystal / Ceramic

- **Crystals**
  - In the ideal case, you have a crystal of piezoelectric material. A crystal is stack of identical bricks. So if we understand the properties of one brick, we can scale up to understand the properities of the whole stack. For example, if one brick weighs 2 lbs, and you have a stack of 500 bricks, then you know that the weight of the whole stack is 2lbs/ brick * 500 bricks = 1,000 lbs. So let's look at one 'brick' of the piezoelectric crystal.

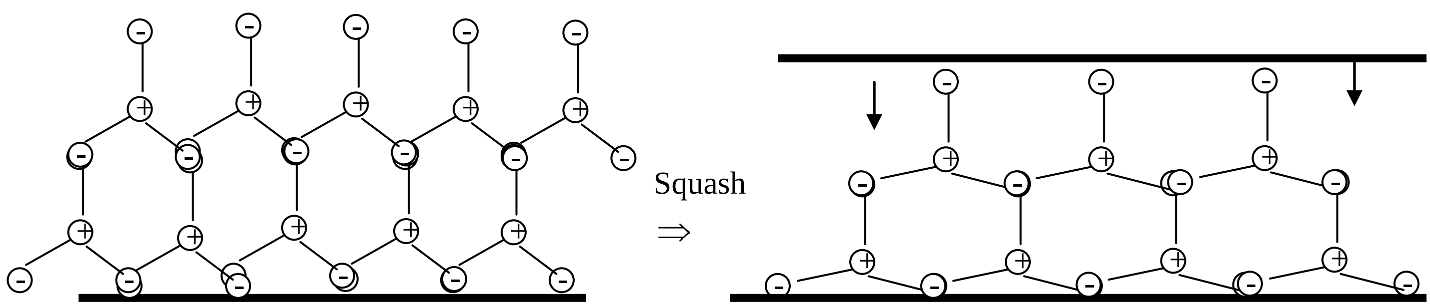
- **Ionic Crystal**
  - One of these ‘bricks’ may look something like this



  - **Charge distribution, net neutral**
    - Each dot is an atom, and the + and – signs indicate that, in the bonding process, some of the atoms some of the atoms have appropriated electrons from the others, making the electron rich atoms slightly – charged and those that are low on electrons are slightly + charged.
    - Say this is electrically balanced, the central atom’s + charge is equal and opposite to the sum of the other three atom’s – charges. This is also symmetric, with the + charge right in the middle.
  - **Mechanical Deformation**
    - Now say you set this ‘brick’ on a table top and you try to squash it. The easiest place for it to give is to widen its ‘legs’.



    - Look at the charge distribution, that + charged atom is much closer to the bottom than before, the top region is a little – charged and the bottom region is a little + charged. This creates a voltage difference across the brick. Now imagine a whole pile of bricks.



  - **Sound -> Electrical signal**
    - So let’s see this work. When it is squashed you get a charge build-up, + on one side and – on the other -> Wire this up, and electrons

will be attracted to one side and repelled by the other – a current will flow. Push more, more current, push less, less current, push more again… The current flow varies with the pressure. In this way a piezoelectric ceramic translates variations in pressure – sound, into variations in electricity.

Demo: squeeze piezo wired to o'scope

- **Electric signal -> Sound**
  - In reverse, force a current – charge onto one side and off of the other, and the piezo will compress or expand in response. In so doing it pushes on or pulls back from the air around it.

Demo: drive piezo with function generator

16.2.1.3 Dynamic / electrodynamic / electromagnetic / moving coil

- **Basic principle: magnetic attraction / repulsion of currents**
  - If two opposing currents repel each other and two parallel currents attract, you can imagine varying the current in two parallel wires and making them come together and apart, together and apart,… This translates between an electrical signal and mechanical motion, and that's key to our transducer process. But let's think about how to optimize this.
- **Wire & magnet**
  - A permanent magnet has a permanent current running through it. So it is convenient to replace one of our two wires with a magnet. Then varying the current in the remaining wire will make the wire and magnet come together or separate apart.

Demo: Current Swing in presence of magnet.

- **Foil & magnet**
  - Now, if we increase the amount of current in the presence of the magnet, we increase the force. Providing a broad foil instead of just a wire does this.
  - This also provides a big surface area for pushing around air.

Demo: Foil Speaker

Unfortunately this sounds rather metallic. So we can take another approach.

- **Wire Coil & magnet**
  - The more current carrying wire near the magnet the better, so we just coil up some wire to get a lot of current right there.

Demo: Plug wire into stereo and place over magnet – see it jump

- **Diaphragm & Wire Coil & Magnet**
  - Now we have the same problem with our wire as we do with the string of a guitar – all by itself, it doesn't push enough air.
  - One solution is to attach it something with a bigger surface area - a speaker cone, or for the sake of this demo, a Dixie Cup.

Demo: Sandwich coil between Dixie cups and place over magnet

- **Stereo Speaker**
  - This is the typical arrangement you'll find inside a stereo speaker.
- **Operation**
  - So, I can use this set-up as a speaker by varying the current through the wire, this makes the wire (and diaphragm attached to it) move back and forth & push the air – sound waves.
  - In reverse, sound waves can push the diaphragm (and the wire attached to it). This causes a current to pass through the wire. Thus the set-up can be used as a microphone.