A. Inventing The Oscilloscope

1. While playing with his new light bulb one day Tom Edison discovered that the hot filament emits electrons into the surrounding vacuum. A cool one does not. That discovery is now known as the "**Edison effect**". Certain coatings can make the filament (or **"cathode"**) emit electrons more easily.

2. If a positively charged object is placed in the vacuum near the cathode then the emitted electrons are _____ by it. (attracted, repelled) Such an electron attractor is called an **"anode"**. (The words "cathode" and "anode" were invented for chemists by Michael Faraday. People who aren't so fond of chemistry and/or greek sometimes use the words "filament" and "plate" instead.)

3. A vacuum tube with a hot filament and a plate is a primitive **"diode"**.
   a. Electrons will accelerate through the vacuum from the _____ to the _____ if the hot filament is connected to the _____tive terminal of a power supply and the _____ is connected to the _____tive terminal, because opposite charges _____ and similar charges _____ each other.)
   b. If the power supply is reversed, electrons do *not* flow through the vacuum because they cannot escape from the _____, because that piece of metal is _____. (hot, cool)

4. If the plate in a diode has a hole in it, some of the electrons described in 3a will pass through it and keep going, to form a "beam" of electrons known as a **"cathode ray"**. An "**electron gun**" is a diode with a small hole in its plate, used to generate a beam of electrons. Early investigators noticed a faint blue glow where cathode rays strike a glass surface. Further experiments revealed that the glowing spot on the glass can be made much brighter if the glass is coated with zinc sulfide or certain other materials called "phosphors". Zinc sulfide emits green light, and other phosphors glow with different characteristic colors. If a thin beam of electrons is aimed at such a surface (called a "screen") we expect to see a glowing _____ _____ on the screen. (Insert an adjective and a noun.)

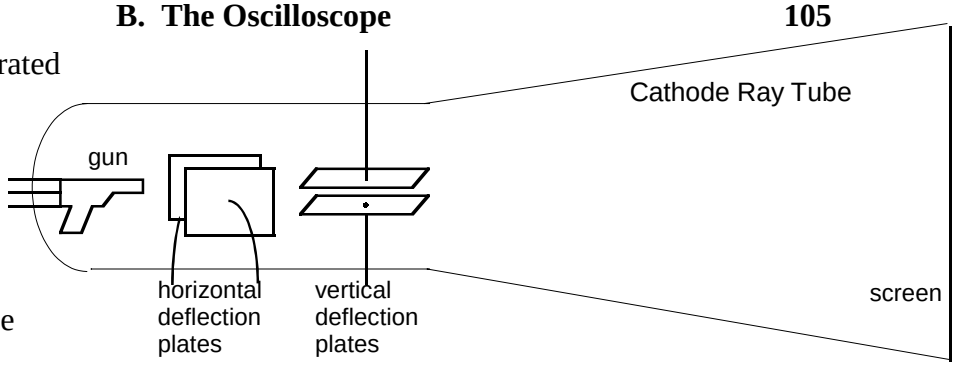
5. An electron beam can be **deflected** by passing it between two oppositely charged objects. Using the steps below, make a big sketch on the back of this page to illustrate that trick.
   a. Start by sketching an electron gun shooting a beam of electrons from left to right across your paper. Let the beam be represented by a dotted line.
   b. Near the gun draw two fairly short straight lines parallel to the beam to represent two oppositely charged objects called "deflection plates". *Remember that the beam passes between them.*
   c. Far to the right of the deflection plates make a vertical line representing the screen.
   d. If the upper deflection plate is positively charged and the lower one is negatively charged then the electrons in the beam will experience a ____ward electric force while passing between the plates.
   e. Does 5d contradict 3a? ___
   f. While the electrons are passing between the charged deflection plates they must follow a _____ path. (straight, curved) *Please indicate that part of the path clearly with a dotted line.*
   g. Does the force in 5d still act when the electron is no longer between the plates? _____ Does the electron's velocity continue to change after that force stops acting on the moving electron? ____
   h. Does the velocity change suddenly at the moment when the force begins acting or stops acting? ___
   i. If the velocity of an object is constant then the path that it follows must be _____. (curved, linear)
   j. Using 5d-5i, extend the dotted line that you began in 5f. Show where the beam hits the screen.

6. During the short time interval when the electrons are between the deflection plates they accelerate. *Does 5f agree?* ____ According to the definition of "acceleration" on RS III, the product of the electron acceleration and the time interval must be called _____ __ _____ That product is a vector directed toward the ____tive plate. Do #2, 5d & 5j all agree with that answer? ____

7. Use drawing instruments to make a sketch like #5 but with *three* dotted lines to show the electron beam with three different voltages (zero, small voltage, and greater voltage) between the two deflection plates. Make all three beams originate from the same location, with the same velocity. Label the three places where those three beams hit the screen. (Use 5d, 5f, 5g, 5h,and 5i.)

8. It is easy to prove that the amount of beam deflection is proportional to the deflection voltage. Therefore ***an oscilloscope is a very fast voltmeter.*** (That fact is recorded on RS ___.) -If the deflection voltage changes gradually, then the green spot will gradually _____. -If the deflection voltage changes rapidly and periodically then the pattern on the screen will resemble a _____al ____.

A special kind of CRT is illustrated at the right. In addition to the usual electron gun and ZnS-coated screen, it contains *two* pairs of deflecting plates. One pair is arranged to produce *horizontal* deflection. The other is oriented to produce *vertical* deflection.



1. The "Sawtooth Generator" in an oscilloscope creates a periodically alternating voltage which increases steadily and then drops suddenly. Its voltage vs time graph resembles the teeth of a saw. A sawtooth voltage can be applied to the *horizontal* deflection plates, causing the bright spot on the screen to move.
   * a. Describe that periodic motion in words and sketch a graph of spot displacement vs time.
   b. There are knobs on the oscilloscope labelled VERTICAL GAIN, SWEEP FREQUENCY, FOCUS, and BRIGHTNESS. Which one controls the sawtooth generator frequency? _____
   c. Increasing the sawtooth frequency without changing its amplitude will cause the spot to sweep across the screen with ___creased speed.

2. Sketch the front of an oscilloscope by drawing a rectangle with a smaller rectangle inside it to represent the screen. Make three dots near the bottom to represent three terminals where wires can be connected. Label them V, G, and H. The "G" (ground) terminal is connected to one of the vertical plates, and to one of the horizontal plates. To make the spot move vertically you must create a potential difference between the "V" terminal and the ___ terminal. *Try it with a flashlight cell or other DC power supply.*

3. The "horizontal amplifier" enables you to control the amplitude of the sawtooth voltage just as a guitar amplifier enables you to control the loudness of an electric guitar. You can also disconnect the sawtooth generator by turning the "sweep frequency" knob to its EXTERNAL setting. Then you can apply a signal from any external source to the HORIZONTAL INPUT terminals of the oscilloscope. Use a DC power supply to make the spot jump horizontally to a new position on the screen. Draw a diagram at the right to show how you did it. Label the terminals as in #2.

4. To make the spot on the screen move up or down in #2 you applied a voltage between the ___ terminal and the ____ terminal of the oscilloscope. To control the *amplitude* of such an up-and-down motion you can adjust the VERTICAL GAIN controls. Most oscilloscopes have coarse and fine gain controls.
   a. Sketch the pattern that will appear on the screen if the spot moves from left to right at a constant speed (driven by the sawtooth generator) and at the same time moves up and down with simple harmonic motion due to an alternating voltage applied to the vertical input. *Use a pencil.*
   b. Show (with another sketch) how the pattern must change if the *sweep frequency* is increased. *Use 1c.*
   c. Make a third sketch showing what happens to 4a if the *vertical gain* is increased. *Label the sketches.*
   d. Make another sketch showing what will happen to the pattern in 4a if the sawtooth generator is disconnected by turning the sweep frequency knob to the EXT (external source) setting, as in #3.

5. Sketch an "audio generator" (another rectangle) near your oscilloscope. Label it. Make two dots on the generator to represent its terminals. Then draw two wires connecting the audio generator to the oscilloscope, as in #4. After your plan has been approved, hook it up and test the predictions made in #4. Use a *moderate* generator frequency. If necessary, erase your answers to #4 and *correct* them.
   a. What happens to the graph displayed on the screen when you turn the knob with the vertical arrows?
   b. What does the left-right arrow knob do? What happens if you exchange the connecting wires?
   c. Illustrate the difference between a "sine wave" and a "square wave".

6. Make a sine curve on the screen with amplitude A = 1.0 block. Let "P" represent its period. Hold a piece of string against the screen to form a tangent line at the steepest point. *Illustrate with a sketch.*
   a. How far above the axis does that tangent line intersect a vertical line placed exactly half a cycle to the right of the origin? *Answer in terms of "A". Remember to estimate the uncertainty of your answer.*
   b. Change the sweep frequency or the generator frequency or amplitude. Does that alter 6a? ____
   c. Please illustrate your answer to 6b.
   d. Using 6a, estimate the slope of the tangent line in terms of A and P. Also estimate its uncertainty.
   e. The exact formula for that slope (in terms of A and P) is in #__ on RS VIII. Copy it. Does 6d agree?