Project 1 – Diode Voltage-Current Characteristics (One Week)

BACKGROUND

In this lab assignment, we explore the voltage-current characteristics of the *pn*-junction diode. The focus of the work will be the 1N4007 and 1N4148 diodes found in your lab kit. As discussed in lecture, the *v*-*i* relationship for these common types of diodes is given by the formula

$$i_D = I_S(e^{v_D/\eta V_T} - 1)$$

where i_D and v_D are the current through, and voltage across, the diode, respectively. The constant I_S is called the diode's *scale* (or sometimes *saturation*) current, $V_T = kT/q$ is the thermal voltage, equal to about 25 mV at room temperature, and η is a constant between 1 and 2. In this lab, we'll assume the value $\eta = 1$.

Laboratory Goal:	To plot the voltage-current characteristic of the 1N4007 and 1N4148 diodes, find their values of scale current I_S, and further investigate the properties of diodes.
Learning Objectives:	Diode *v*-*i* characteristic, use of lab equipment, analysis techniques, simple diode circuits.
Suggested Tools:	Variable voltage source, multimeter, oscilloscope, op-amp circuits.

ASSIGNMENT

Level 1: Choose at least two each of the 1N4007 and 1N4148 diodes in your parts kit. For each diode, devise a method for measuring its current vs. voltage characteristic manually (e.g., by taking individual data points).

a) Enter your data points into a spreadsheet or a Matlab program, then plot the *i*-*v* curve.
b) From your collected data, determine the I_S value for each of your diodes.

Question: Do the *i*-*v* curves and I_S values match for each diode having the same part number?

Level 2: Devise a method to plot the *i*-*v* curve of one of your diodes directly on the oscilloscope using the latter's *x*-*y* display mode. Compare with the plot obtained manually. Which do you feel represents more accurate data?

Level 3: Build either an analog-multiplication or analog-division circuit using diodes and some operational amplifiers. Your circuit should be capable of performing the following calculation:

$$v_{out} = B_1\ (v_1 \times v_2)$$

or

$$v_{out} = A_2\ (v_1 \div v_2)$$

where B_1 and A_2 are constants. You may design for any suitable values of B_1 or A_2 that you choose. (Note: B_1 has the dimensions of volts^{-1}, whereas A_2 is dimensionless. See "Tools" below for some helpful ideas.)

Diode Current-Voltage Equation – Alternate Form

The diode equation is often expressed as current i_D versus applied voltage v_D (assuming η = 1):

$$i_D = I_S(e^{v_D/V_T} - 1)$$

This formula gives rise to a very steeply rising curve for values of v_D above a few tenths of a volt. An alternative formula can be derived by taking the base-10 logarithm of both sides of the equation, as follows:

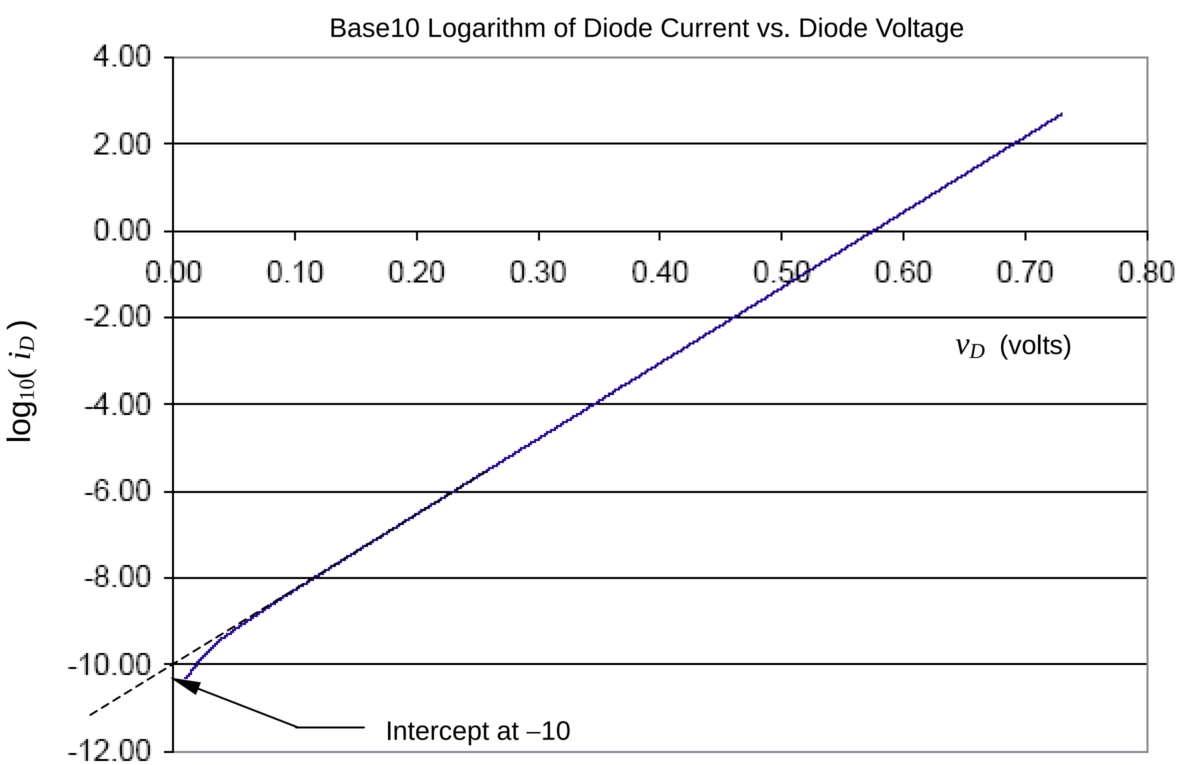
$$log(i_D) = log(I_S) + log(e^{v_D/V_T} - 1)$$

For the case where $v_D >> V_T$, so that the e^{v_D/V_T} term dominates over the –1 term, the above equation simplifies to:

$$y = log(I_S) + \frac{v_D}{V_T}$$

where y = $log(i_D)$

This equation yields a straight-line plot wherein the y-axis intercept is equal to the log of I_S. This concept is illustrated in the following plot made for the case $I_S = 10^{-10}$ A:

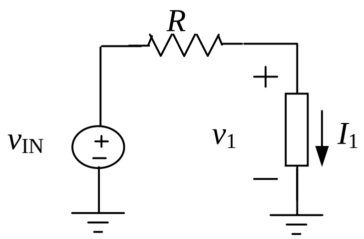


Note that the *actual* diode *i*-*v* curve (solid) deviates from the extension of the straight-line portion (via the dotted line) due to the factor of –1 that we ignored in the diode equation. This factor is negligible for large values, but it's not negligible for very small values of v_D.

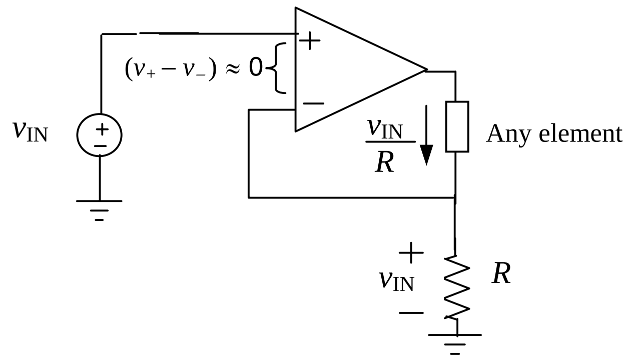
Synthesized Current Source

Forcing a known *current* through the diode and measuring the resulting voltage may provide an easier path to finding the needed data points. This method is *not* a requirement of this lab, just another possible experimental tool that you may choose to use.

Some circuits that synthesize the function of a current source:

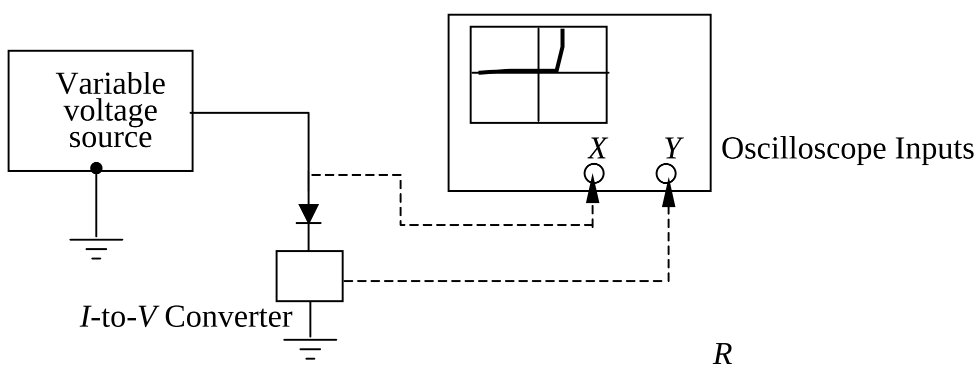


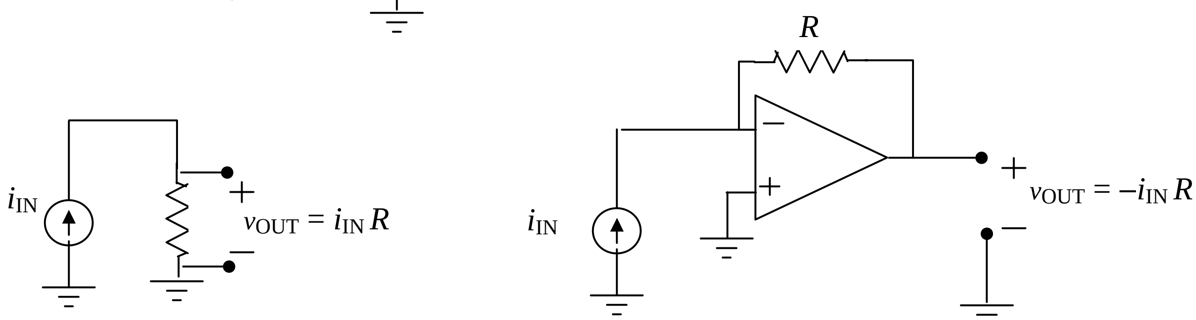
$I_1 \approx \frac{v_{IN}}{R}$ if $v_1 << v_{IN}$



Oscilloscope X-Y Mode

Every oscilloscope has an *x-y* mode in which one of its voltage channels is displayed on the horizontal axis, and the other voltage channel is displayed on the vertical axis. When a scope is operated in the *x-y* mode, the time base is disabled; the screen no longer provides time measurements. Rather, it displays the values of its two input voltages via a dot on the display screen. The displayed volts per division for each axis corresponds to the volts-per-division setting of the associate input channel. A current-versus-voltage curve can be readily displayed if some means exists for converting measured current into a useable voltage relative to ground. The following diagram illustrates one possible method for displaying an *i-v* curve:

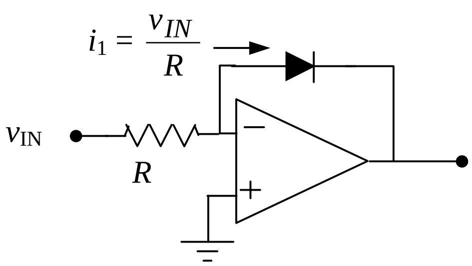




Possible Current-to-Voltage Converters

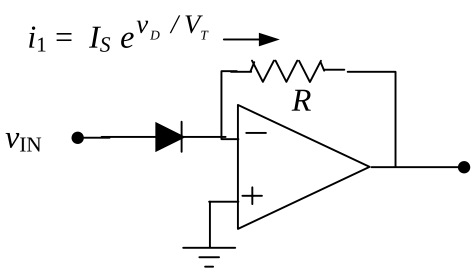
Log and Anti-Log Amplifiers

The following two amplifier circuits enable the logarithmic manipulation of signals by using the exponential characteristic of the diode. For each circuit, we make the assumption that the diode's *i*-*v* characteristic can be represented by the simplified equation $i_D \approx I_S e^{v_D / V_T}$. The latter is valid in the diode's forward-biased region of operation.



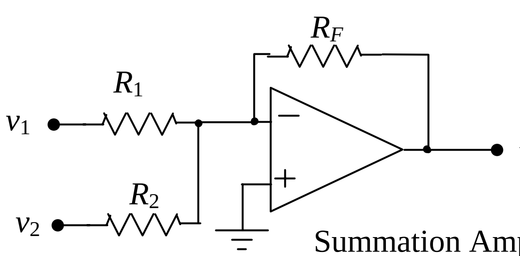
$$v_{OUT} = -V_T \ln\left(\frac{i_1}{I_S}\right) = -V_T \ln\left(\frac{v_{IN}}{I_S R}\right)$$

Logarithmic Amplifier



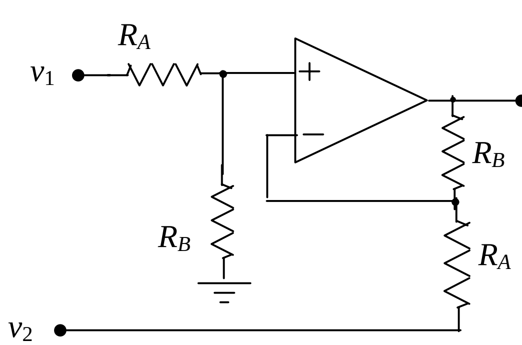
$$v_{OUT} = -i_1 R = -I_S R\, e^{v_D / V_T}$$

Exponential (Anti-Log) Amplifier



$$v_{OUT} = -\frac{(v_1 R_1 + v_2 R_2)}{R_F}$$

Summation Amplifier



$$v_{OUT} = \frac{R_B}{R_A}(v_1 - v_2)$$

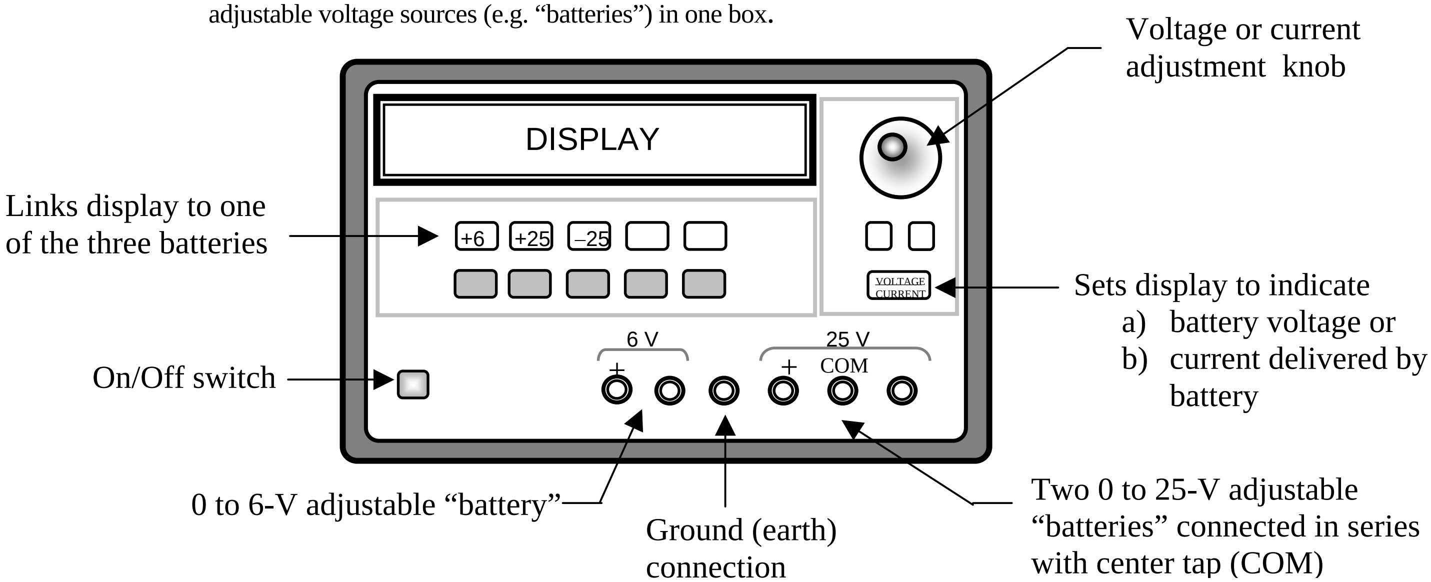
Difference Amplifier

Bench Top Instruments (Review from EK307)

Power Supply: The HP 3631A power supply located on your lab bench is an instrument that simulates, via internal electronics, power available from three separate, adjustable voltage sources. You may think of these voltage sources as independent batteries whose values you may adjust via the knob in the upper right-hand corner of the instrument. The functions of the various buttons of the supply and the arrangement of the simulated batteries with respect to the connection terminals on the front panel are shown in Fig. 1.

Multimeter (Review from EK307): The HP 34401 Digital Multimeter (DMM), shown in Fig. 2, is capable of taking many types of measurements, including voltage, current, and resistance. The equivalent internal resistances appearing between the (+) and (–) voltmeter terminals is 10 MΩ, and between the IN and OUT current-measuring terminals about 5 Ω.

Figure 1 - The HP (Agilent) 3631A Triple Output Power Supply contains three synthesized, adjustable voltage sources (e.g. "batteries") in one box.



What's Inside

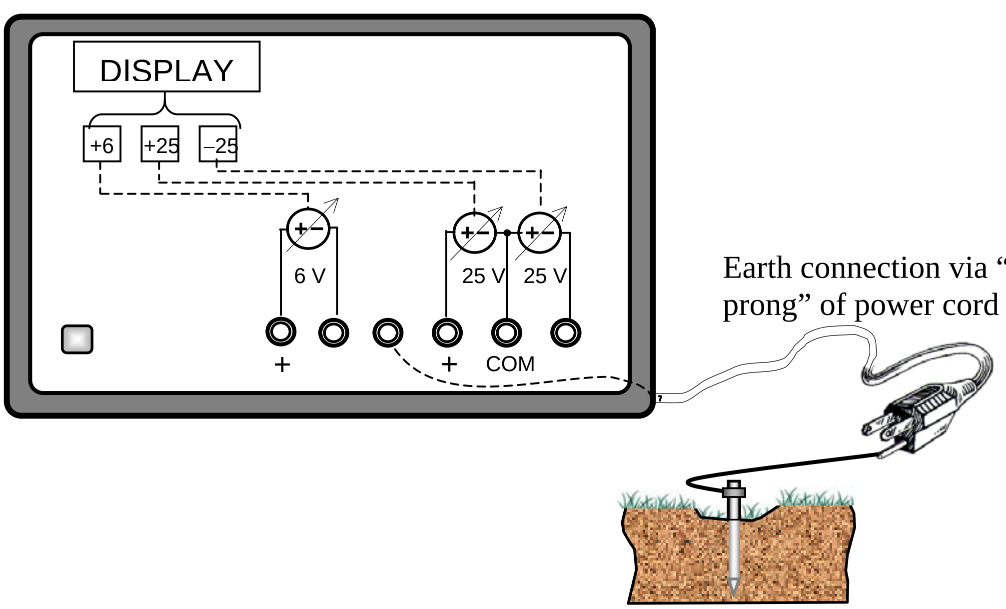
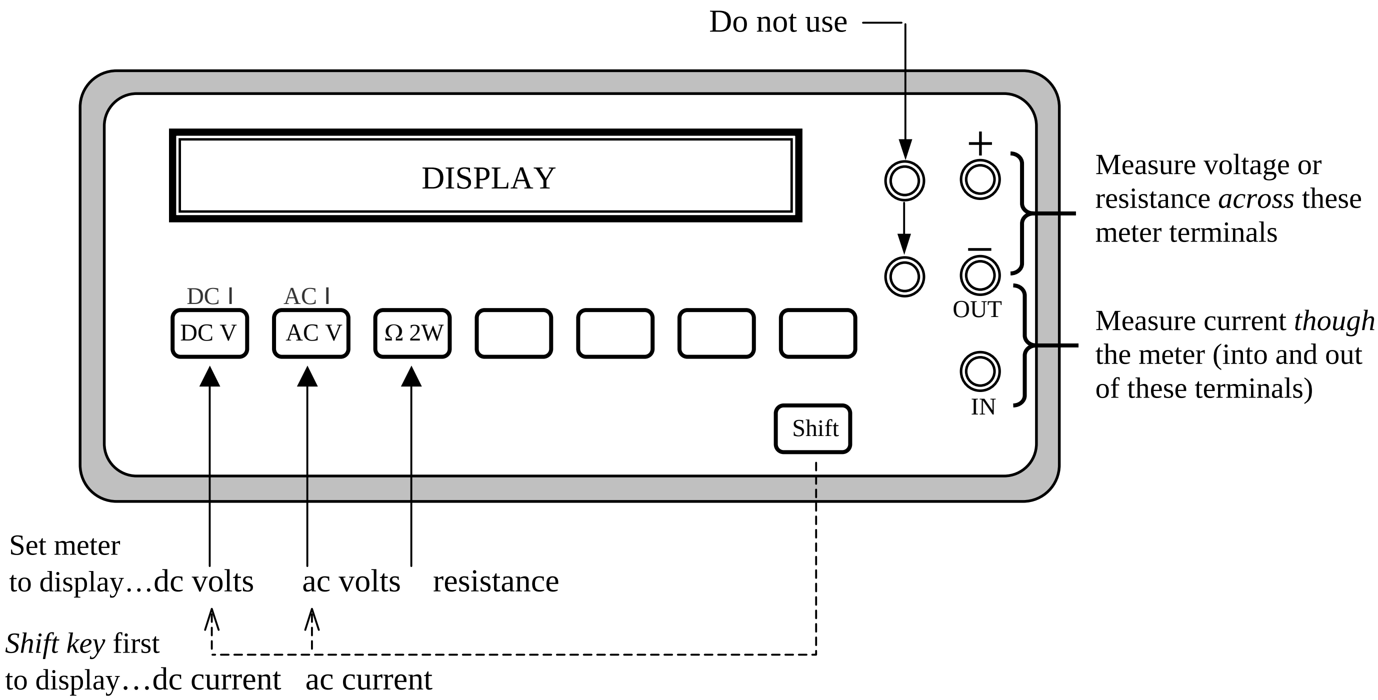
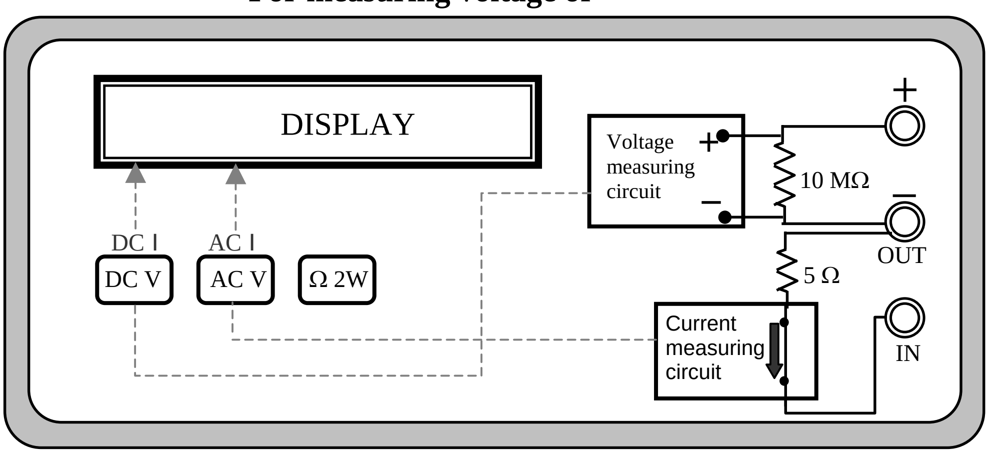


Figure 2 - The HP 34401 Digital Multimeter can be used to measure voltage, current, and resistance.



What's inside …

For measuring voltage or



For measuring resistance