

What is the buoyant force on the block in the oil?

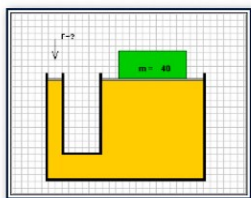
Now, suppose the wood block is put in a mixture of water on the bottom with oil on the top (the oil floats on the water and doesn't mix with the water).

- g. What do you expect will happen? Why?
- h. Try it. Is more or less of the block submerged in water in this case compared with the block simply floating in water (without oil)? Why?
- i. One way to look at what happened is to measure the pressures. Find the pressure at the bottom of the block and at the top of the block.
- j. What is the pressure difference and thus the net buoyant force on the block?
- k. In order for a block to float only in water (with air on top), to get the same pressure difference to support the block, why does the block need to be lower in the water? (Think about the density of air compared with the density of oil and, therefore, the change in pressure with depth in air and in the oil.)

Another way to look at this is to compare the buoyant forces.

- l. In comparison with the block floating in water only, has the buoyant force increased, decreased, or stayed the same?
- m. What is the volume of water that the block displaces?
- n. What is the weight of that water?
- o. What is the volume of oil that the block displaces?
- p. What is the weight of the displaced oil?
- q. How do those two compare with the weight of the block?

### Problem 14.1: Hydraulic lift

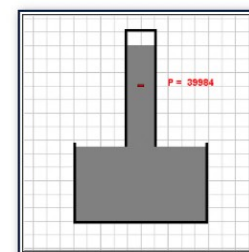


Use a JavaScript-enabled browser to open and run this Problem.

The animation shows a model of a hydraulic lift. The gray areas are circular lids on top of the yellow fluid inside the lift (**position is given in centimeters**).

- a. What force is required on the left side to support the 40-kg mass?
- b. If the mass is lifted up 1 cm, how far down does the fluid on the left need to be pushed?

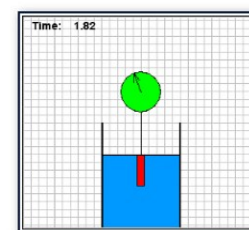
### Problem 14.2: Mercury barometer



Use a JavaScript-enabled browser to open and run this Problem.

A tube contains a column of mercury while the bottom container of mercury is open to the atmosphere to form a mercury barometer (**position is given in tenths of meters and pressure given in pascals**). What is the atmospheric pressure?

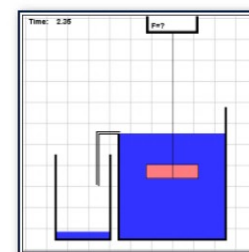
### Problem 14.3: Find the density of object in water



Use a JavaScript-enabled browser to open and run this Problem.

Find the density of the object being immersed in the water bucket. The initial reading on the spring scale is 19 N. One full revolution of the spring scale represents a change of 10 N.

### Problem 14.4: Pressure and buoyant force of block suspended in water



Use a JavaScript-enabled browser to open and run this Problem.

The blue liquid is an oil with  $\rho = 850 \text{ kg/m}^3$  (**position is given in centimeters and the dimension of the oil containers into the screen is 20 cm**).

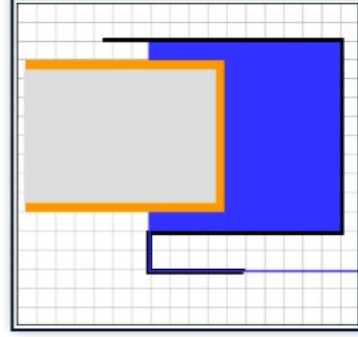
- a. If the mass is 150 g, what is the tension on the wire at the following times: 0.

4 s, 1.5 s and 4 s?

- b. What is the gauge pressure at the top of the mass at  $t = 1.5$  s and  $t = 4$  s?
- c. Some students find the answers to questions (a) and (b) (the tension in the wire and the gauge pressure) inconsistent. Explain why they are consistent with each other.

Note that gauge pressure is the difference in pressure due to the surface of the water (the absolute pressure would be the pressure due to the atmosphere at the surface plus the pressure due to the water).

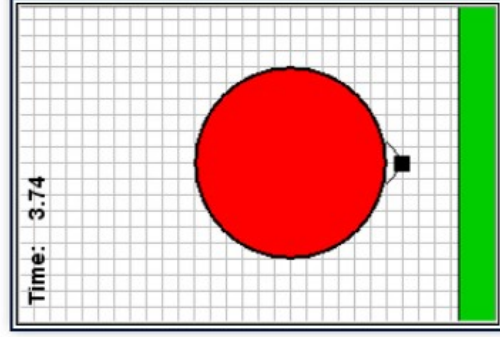
### Problem 14.5: How much weight will a boat hold?



[Use a JavaScript-enabled browser to open and run this Problem.](#)

How much more mass can this “boat” sitting in water hold and still float? The dimension of the “boat” into the screen is 8 cm (**position is given in centimeters and time is given in seconds**).

### Problem 14.6: Find the density of a fluid



[Use a JavaScript-enabled browser to open and run this Problem.](#)

A block is lowered into a liquid as shown (**position is given in centimeters, time is given in seconds, and force is given in newtons**). The dimension of both containers into the screen is 20 cm. The dimension of the block into the screen is 10 cm. What is the density of the liquid?

parallel combination of a 2- $\Omega$  resistor and a 3- $\Omega$  resistor.

Consider a Kirchhoff loop consisting of the battery and the two 2- $\Omega$  resistors. It doesn't matter where we start, as long as we come back to the same spot. Let's go clockwise around the loop starting at the bottom left corner.

$$+ 16V - (2\Omega) * I - (2\Omega) * 3I / 5 = 0$$

$$+ 16V = (10\Omega) * I / 5 + (6\Omega) * I / 5$$

$$+ 16V = (16\Omega) * I / 5.$$

Yes  $I = 5$  A.

Use the animation and follow the energy of the unit charge as it passes through each circuit element. Each voltage drop represents the amount of energy that is lost when the charge passes through a circuit element. This demonstrates that, as charge flows around a complete loop, the gains in energy are always offset by losses. The total change in energy is zero.

### Exploration 30.1: Circuit Analysis

$V_A$ (V)	$V_B$ (V)	$V_C$ (V)	$V$ Battery (V)
+3.33	+3.33	+10.00	+10.00

Exploration 30.1: Use a JavaScript-enabled browser to open and run this Exploration.

The exploration begins with four identical lightbulbs connected to a battery. The voltage is given in volts and current is given in amperes). Often, you will be asked

to find the current through, the voltage across, the resistance, and/or power consumed by a given bulb (or group of bulbs). To solve these types of problems, you will use Ohm's law,  $V = IR$ , and an equation for power,  $P = IV$  or  $P = I^2 R$ , where  $V$  is the voltage,  $I$  is the current,  $R$  is the resistance, and  $P$  is power. You will also need to use two rules that are based on conservation

- **current in = current out.** Since charge is not created or destroyed (conservation of charge), charge flowing into some point must also flow out unless there is a circuit element that can store charge (a capacitor).
- **$\Delta V$  through a complete loop = 0.** The electric force is a conservative force (which is why we can define an electrostatic potential). This means that if you start at one point in a circuit and add up all the increases and subtract all the decreases in potential as you trace a complete loop, then when you get back to the place you started, the potential must be the same.

Let's use these rules for the initial circuit. The brightness of the bulbs is an indication of the current through the bulbs (brightness actually goes as  $I^2 R$ ).

- Rank the bulbs in order of brightness (and therefore in order of current through them), from highest to lowest.
- Show the currents (in the data table) through the bulbs to check your answer. The arrows indicate the direction of the current through the bulbs.
- Find the current through bulb D by determining how much current is coming into the node (the dot where the wires come together) below bulb D. The current is coming from bulbs A and B.
- Check your answer by verifying that the current coming into the node below bulb D (from bulb C and bulb D) is equal to the current going out of the node and into the battery.

Now consider the voltage across various elements. Show the voltages (in the data table) across the bulbs.

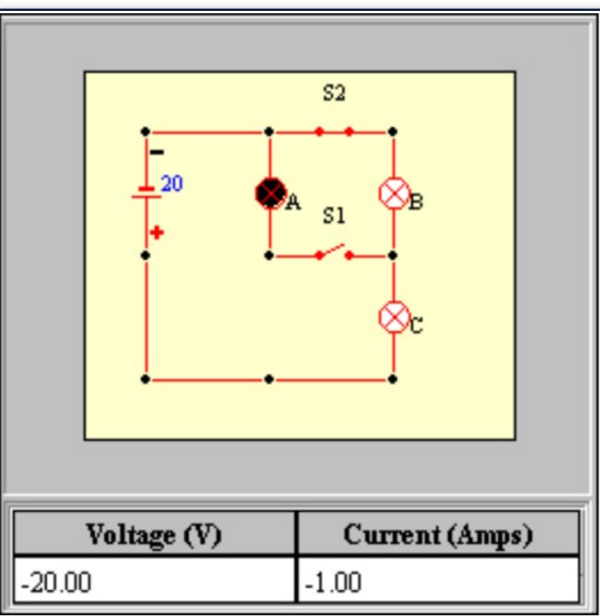
- Why is the voltage across bulb C the same as the voltage across the battery? (think about tracing a path around the outside "loop" of the circuit.)
- Why is the voltage across bulb A equal to the voltage across bulb B?
- Find the voltage across D by picking a complete loop to trace.

→ bulb A → bulb D → battery) OR (battery → bulb B → bulb D → battery) OR (bulb C → bulb D → bulb A) OR (bulb C → bulb B) and finding the value of the voltage for bulb D that the change in potential equal to zero.

$V = IR$ , what is the resistance of bulb D? (Check that it is the same as A, B, and C).

What is the power dissipated by bulb D?

### Exploration 30.2: Lightbulbs



Exploration 30.2: Use a JavaScript-enabled browser to open and run this Exploration.

When both switches are closed, bulbs A and B are dimmer than bulb C. When you can close and open switches to determine the resistance of the circuit. The current and voltage readings show the current through the battery and the voltage across the battery (**voltage is given in volts and current is given in amps**). In order to solve such problems, you can always use Kirchhoff's laws. If it is possible, a faster way to work problems is in terms of the effective resistance of the network of resistors. You consider the resistors that are in series. It is, however, worth looking at the circuit in detail first, before diving into equations, to see if there is a way to solve the problem conceptually and to solve it faster.

When both switches are closed, bulbs A and B are dimmer than bulb C.

This should not be surprising because the current through bulb C is the sum of the currents through A and B. Open one of the switches and leave the other one closed. Now bulb C is in series with one of the bulbs (which one?). Notice that the current from the battery is less, but that either bulb A or bulb B is brighter than it was before.

a. Why?

Go back to the case in which both switches are closed and notice that bulbs A and B look to be the same brightness. If the brightness were exactly the same, they would have the same resistance.

b. With switch 1 open and switch 2 closed, what is the current?

c. What about with switch 1 closed and switch 2 open?

d. How does this “prove” that bulbs A and B are identical?

e. Furthermore, when one switch is open and one closed, how does the brightness of bulb C compare with the bulb it is in series with?

f. What does that indicate?

Now for some math.

g. Since  $R_A = R_B$ , explain why, when both switches are closed, the effective resistance of the circuit is  $1 / (2R_A) + R_C$ . (Hint: with both switches closed, bulbs A and B are in parallel with each other).

h. When both switches are closed, use the voltage across the battery and the current through the battery to find the value of the effective resistance.

i. With one switch open and one switch closed, use the voltage across the battery and the current through the battery to find the value of the effective resistance. The effective resistance is equal to  $R_A + R_C$  (or  $R_B + R_C$ ).

j. Solving these equations, you should find that all the bulbs are identical (something you surmised from the brightness of the bulbs).

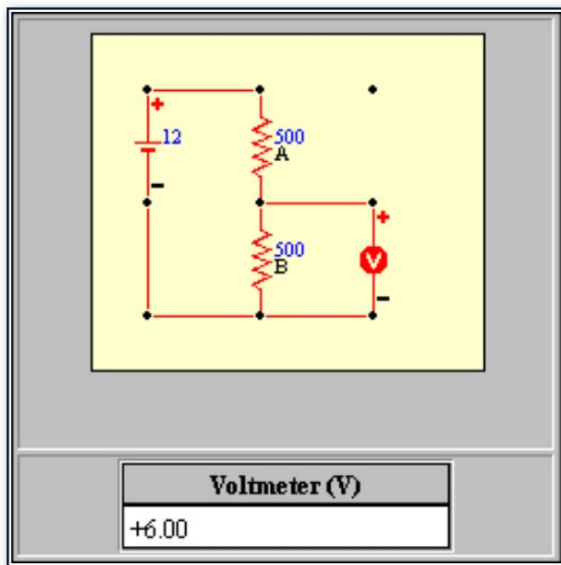
Notice that in this problem, trying to understand conceptually what was happening helped to guide the problem-solving process. Although the Kirchhoff loop method will work, they are not necessarily the easiest way to solve a problem.

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- h. When both switches are closed, use the voltage across the battery and the current through the battery to find the value of the effective resistance.
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- j. Solving these equations, you should find that all the bulbs are indeed identical (something you surmised from the brightness of the bulbs).

Notice that in this problem, trying to understand conceptually what was happening helped to guide the problem-solving process. Although the Kirchhoff loop rules will work, they are not necessarily the easiest way to solve a problem.

### Exploration 30.3: Designing a Voltage Divider



Exploration 30.3: Use a JavaScript-enabled browser to open and run this Exploration.

When working with circuits, not only do you want to be able to figure out what a circuit that is already built is doing, you may want to design a circuit for a specific task. In this case the task is to design a circuit that is a voltage divider with a particular output voltage (the **output voltage is given in volts and resistance is given in ohms**). You have a 12-V supply that can give you 1 W of power, and you need a 4-V output with as much power as

possible. The resistors that you have can dissipate 1 W of power.

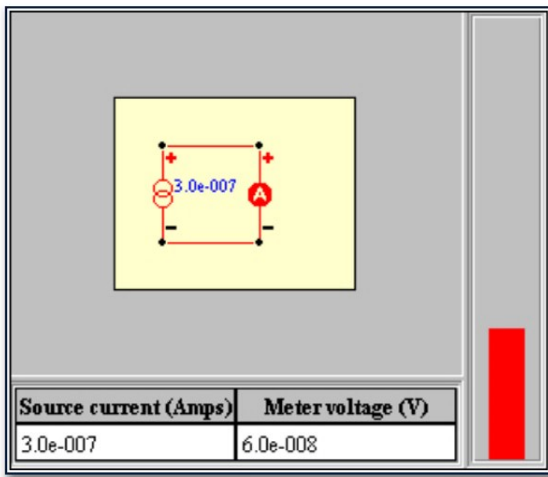
To divide the voltage, we can put the power supply in series with two resistors and then use the voltage across one of the resistors to be our 4-V output.

- a. What ratio of resistors do you need to divide the supply voltage by one third? In other words, how many times bigger (or smaller) should resistor A be than resistor B to get an output of 4 V? Try it.
- b. Once the ratio is set up, do you have the maximum available power? To determine this, figure out the power used from the voltage source ( $P = VI$ ). To get the maximum power (at a fixed voltage), should you increase or decrease the resistance in the circuit?
- c. What is the limit on the total resistance ( $R_A + R_B$ ) and, therefore, the limit on the resistance of each resistor? Try it.
- d. Try using a smaller value of resistance. Does the power supply burn up? (Fortunately, you can simply restart the animation and try again).
- e. Double the values of  $R_A$  and  $R_B$ . How much power does this circuit now draw from the battery?

Now that you have determined convenient values of  $R_A$  and  $R_B$  that produce a 4-V output, replace the voltmeter with a lightbulb. (Adding a power-consuming circuit element is sometimes referred to as adding a “load.”)


- f. When this lightbulb is added, what is the voltage across the lightbulb?
- g. Why is it less than 4 V?
- h. If you increase  $R_A$  and  $R_B$  more, what happens to the voltage across the lightbulb? Why? This is the reason voltage dividers like this are made from resistors that are as small as possible.

### Exploration 30.4: Galvanometers and Ammeters



Exploration 30.4: Use a JavaScript-enabled browser to open and run this Exploration.

An ammeter measures current through a device and therefore must be in series with whatever element you want to find the current through. In this animation we will contrast the behavior of ideal and real ammeters by exploring the way a basic galvanometer works and finding how you can build an ammeter using a galvanometer (voltage is given in volts and current is given in amperes).

A galvanometer is a very sensitive meter that deflects when a small amount of current passes through it. (The current often goes through a coil that induces a magnetic field that causes an indicator needle to move. We use a red indicator bar instead of a needle.) In the galvanometer animation you can enter a source current and push the "ammeter" button. The current source is shown using two interlocking circles, . The indicator bar on the right shows the maximum current that can pass through the galvanometer without damaging the instrument.

- Change the source current so that the indicator is at 50%. What is the current through the galvanometer and the voltage drop across the galvanometer? (This voltage drop is due to the internal resistance of the coil.)
- What, then, is the maximum current that should go through the galvanometer (to just get the red bar to 100% of the screen)?
- What happens if you exceed the maximum current rating?

Notice that a galvanometer is a very sensitive current meter. They are often rated not by the maximum current, but by the internal resistance and the associated voltage drop at the maximum current.

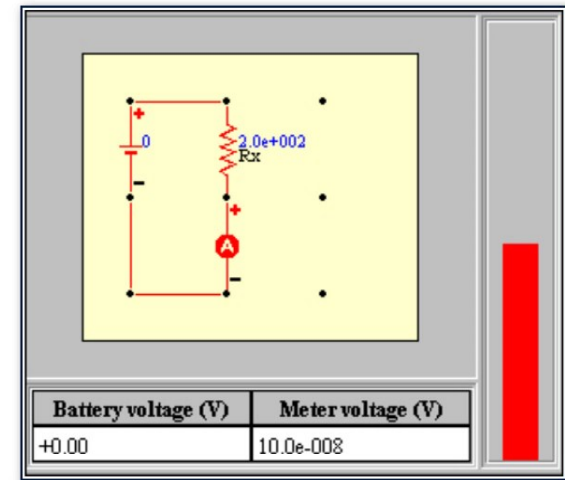
- Show that the internal resistance of this galvanometer is  $0.2 \Omega$  and the voltage drop at maximum current is  $0.2 \mu\text{V}$ .

Suppose we want to use a galvanometer to measure currents up to 1mA. We know that


we want full-scale indication (bar at 100%) at 1mA and half-scale at 0.5 mA and so we need for our meter to be made up of the galvanometer plus a resistor in parallel. This configuration is called an ammeter. For the galvanometer to just read full scale at 1 mA, only  $1 \mu\text{A}$  of current can go through the galvanometer, and the other  $999 \mu\text{A}$  must go through the parallel resistor.

- If the voltage drop is  $0.2 \mu\text{V}$ , what value does the resistor in parallel need to have?
- Try the value (for  $R_x$ ) and then test by adjusting the power supply to see if you get the appropriate indication over the range of values (e.g., you should get half-scale indication for a source current of 0.5 mA; 80% of the bar would indicate a source current of 0.8 mA, etc.). Here use the "ammeter" button.
- What would the ideal value of the internal resistance for an ammeter be, and why?

### Exploration 30.5: Voltmeters



Exploration 30.5: Use a JavaScript-enabled browser to open and run this Exploration.

A voltmeter measures the voltage across a circuit element and therefore is put in parallel with that element. We can construct a voltmeter by placing a large resistor in series with the galvanometer indicated by  (an ammeter symbol) in the circuit because a galvanometer and an ammeter are essentially the same (see Exploration 30.4). In this example the galvanometer shows a full-scale indication at a current of  $1 \mu\text{A}$ , and the internal resistance of the galvanometer is  $0.2 \Omega$ .

- What voltage across the galvanometer produces a full-scale reading?

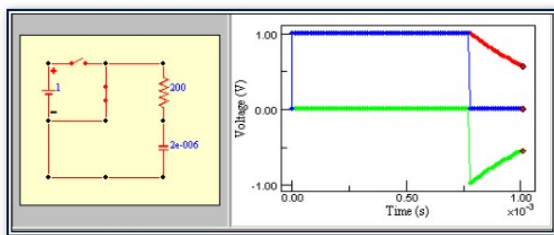
If we want to measure battery voltages of up to 2 V, we'd want the galvanometer needle to give a full-scale indication at this voltage. This means that  $0.2 \mu\text{V}$  must drop

galvanometer (with a current of  $1 \mu\text{A}$ ), while  $1.9999998 \text{ V}$  must drop across resistor.

Calculate the value of the series resistor required to produce a full-scale reading when the input voltage is  $2 \text{ V}$ . Test to see if you get the appropriate reading for a range of battery voltages. (Use the “set values” button.) Specifically, check that, for a battery voltage of  $1 \text{ V}$ , you get a half-scale reading on the indicator bar.

What would the ideal value of internal resistance for a voltmeter be and why?

### Exploration 30.6: RC Time Constant



Exploration 30.6: Use a JavaScript-enabled browser to open and run this Exploration.

In this animation you can close and open switches to see what happens to the voltage across the capacitor (red), the voltage across the resistor (green), and the total voltage across the capacitor plus resistor (blue). Initially, the capacitor is charged. After “play,” you should throw the switches (**voltage is given in volts and time is in seconds**).

Adjust the switches so that you can get a good graph of the capacitor discharging and charging.

How much time (approximately) does it take the capacitor to charge and discharge?

Double the battery voltage. How much time does it take to charge and discharge?

Double the capacitance and measure the time to charge and discharge.

Double the resistance and measure the time to charge and discharge.

The time of  $RC$  (resistance times capacitance) is the  $RC$  time constant for the circuit characteristic time. Set the battery voltage to  $1 \text{ V}$ .

When the time equals  $RC$  after throwing the switch, what is the capacitor voltage when it is discharging? When it is charging?

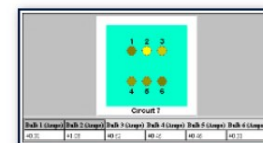
Compare your measurements to the values found from the equations for a charging or discharging capacitor:

$$\text{Charging: } V = V_0(1 - e^{-t/RC}),$$

and

$$\text{Discharging: } V = V_0e^{-t/RC}.$$

### Problem 30.1: Draw the schematic diagram



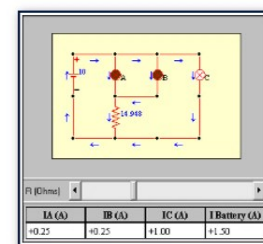
Use a JavaScript-enabled browser to open and run this Problem.

You are given arrangements of identical lightbulbs with the wires connecting them hidden from view. Determine how the lightbulbs are connected by unscrewing and/or screwing the bulbs. All bulbs are initially screwed in their sockets, and the current through each bulb is given in the table (**current is given in amperes**).

Draw a schematic diagram representing the hidden circuit for each animation.

- Circuit 1 - Three Bulbs
- Circuit 2 - Three Bulbs
- Circuit 3 - Four Bulbs
- Circuit 4 - Four Bulbs
- Circuit 5 - Five Bulbs
- Circuit 6 - Six Bulbs
- Circuit 7 - Six Bulbs

### Problem 30.2: Switched light bulbs



Use a JavaScript-enabled browser to open and run this Problem.

The circuit shown contains three lightbulbs, an ideal battery, and a variable resistor. Answer the following questions by varying the resistance and examining the current and voltage across each circuit element (**voltage is given in volts, current is given in amperes, and resistance is given in ohms**).

Why do you change the resistance, what happens to bulbs A, B, and C?

Why doesn't the brightness of bulb C change?

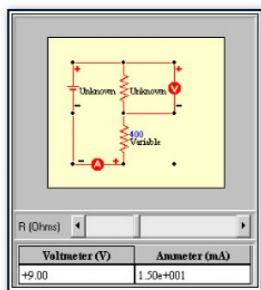
Why do the currents change in the way that they do?

Why does the voltage of the battery change? Why or why not?

Why do the voltages across the bulbs change the way that they do?

### Problem 30.3: Find resistance, battery voltage and power

ended



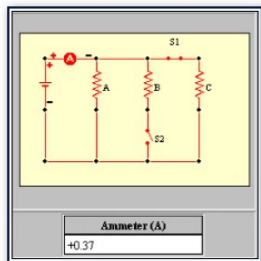
Use a JavaScript-enabled browser to open and run this Problem.

Answer the following questions for each circuit in this animation. Assume an ideal battery (no internal resistance) and ideal meters but note that the battery and unknown resistor are different for each circuit (**electric potential is given in volts and current is given in milliamperes**). Use the slider to change the variable resistor.

What is the resistance of the unknown resistance and the voltage of the battery in each circuit?

What is the range of power dissipated for each circuit over the full range of variable resistance values?

### Problem 30.4: Rank resistances

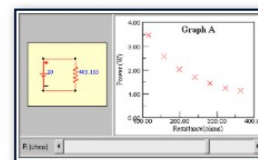


Use a JavaScript-enabled browser to open and run this Problem.

Rank the resistances (from smallest to largest) in each of the two circuits (**ammeter is given in amperes**).

Circuit 1

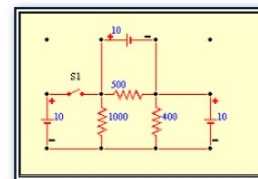
### Problem 30.5: Identify the correct graph



Use a JavaScript-enabled browser to open and run this Problem.

Assume an ideal battery. Vary the resistor and explain which of the graphs are correct and which are incorrect. Pay attention to the labels on the axes (**electric potential is given in volts, current is given in amperes, resistance is given in ohms, and power is given in watts**).

### Problem 30.6: Bad circuits

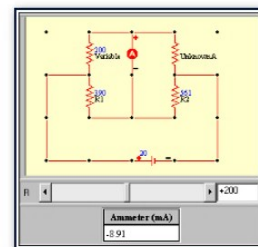


Use a JavaScript-enabled browser to open and run this Problem.

What is wrong with these circuits? Close the switches to see what happens and then explain what is wrong. Note which circuit elements are destroyed (**electric potential is given in volts and resistance is given in ohms**). Choose a new circuit after a circuit element is "destroyed."

- Circuit 1
- Circuit 2
- Circuit 3 (Hint: What might the power rating be on the resistor?)

### Problem 30.7: Wheatstone bridge



Use a JavaScript-enabled browser to open and run this Problem.

The animation shows a "Wheatstone bridge," which is used to measure unknown resistors. Assume an ideal battery (no internal resistance) and ideal meters (**resistance is given in ohms, electric potential is given in volts, and current is given in amperes**).

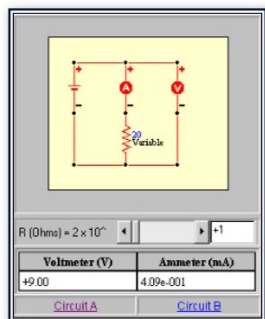
es). Begin the animation (with unknown resistor A) to read the current on er. In a Wheatstone bridge you adjust the variable resistor until the ammeter then you can calculate the value of the unknown resistor.

What is the unknown resistor in this case?

Develop an algebraic expression for the unknown resistance as a function of  $R_1$ ,  $R_2$ , and the variable resistor.

Use your expression to quickly calculate unknown resistor B and unknown resistor C.

### Problem 30.8: Find the internal resistance of voltmeter and ammeter



Use a JavaScript-enabled browser to open and run this Problem.

Circuit A and B are different configurations of the same circuit elements. Assume the battery is ideal (no internal resistance). Pick an animation to show the voltage and current through the meters (**voltage is given in volts and current is given in milliamperes**).

Use the data from Circuits A and B to determine the internal resistance of the ammeter and the internal resistance of the voltmeter. What are the unknown resistances that are used in both circuits. You can vary the resistor in circuits A and B (the variable resistor value).

Which circuit should you use to find the resistance of the ammeter? Which circuit should you use to find the resistance of the voltmeter? Why?

Determine which circuit you will use to find the resistance of the ammeter, and keep in mind the ideal resistance of an ammeter (ideally  $0 \Omega$ ; why is this not the case? resistance of an ammeter?) and pick your variable resistance appropriately. When a very small resistance is in series with a very large resistor, the voltage drop across the small resistor will not be measurably different than the voltage drop across both of them, and the same is true for your determination of the resistance of a voltmeter.

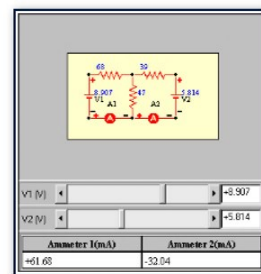
What is the resistance of both the ammeter and the voltmeter?

What if you don't know the internal resistance of the meters or the value of the variable resistor (which is often the case), and you simply want to divide the

voltmeter reading by the ammeter reading to determine the unknown resistance, which circuit, A or B, is the best for measuring small resistances?

d. Which circuit, A or B, is the best for measuring large resistances? Explain.

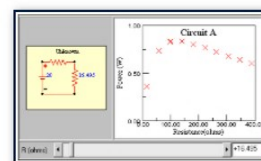
### Problem 30.9: Find internal resistance of battery in a network



Use a JavaScript-enabled browser to open and run this Problem.

The batteries shown are not ideal (that is, they have internal resistances) but are otherwise identical. Assume ideal meters (**current is given in milliamperes and voltage is given in volts**). Vary the battery voltages and find the internal resistances. The internal resistance is the same for both.

### Problem 30.10: Find resistance from power graph



Use a JavaScript-enabled browser to open and run this Problem.

Assume an ideal battery. The graph shows the power dissipated by the variable resistor as a function of resistance (**resistance is given in ohms and power is given in watts**).

- For Circuit A, what is the value of the unknown resistor?
- What is the value of the power dissipated by the variable resistor when its resistance is equal to the unknown resistor?
- Move the slider to vary the resistance. When the variable resistor is equal to the unknown resistor, how does the power dissipated by the variable resistor compare to the power dissipated when the variable resistor is not equal to the unknown resistor?
- How can this help you find the unknown resistances in Circuit B and Circuit C?
- What are the unknown resistances in those circuits (to within about 10%)?

### Problem 30.11: RC circuit: rank the resistance of the light bulbs

$$t = (a^2 + x^2)^{1/2}/v_1 + [b^2 + (d-x)^2]^{1/2}/v_2$$

and the path that minimizes the travel time between the two points, solve

$dt/dx = 0$ . Why?

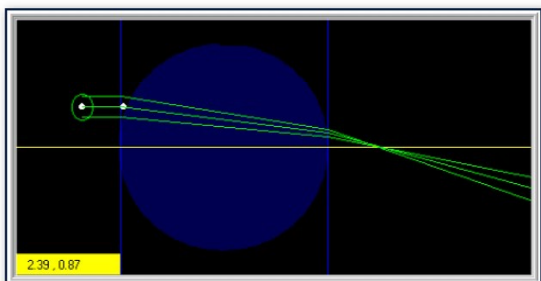
When you solve for  $dt/dx = 0$ , show that you get

$$x/v_1(a^2 + x^2)^{1/2} = (d-x)/[v_2(b^2 + (d-x)^2)^{1/2}]$$

show (make the necessary substitutions) that this is the same as Snell's law,

$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

### Problem 34.5: Index of Refraction and Wavelength



Exploration 34.5: Use a JavaScript-enabled browser to open and run this Exploration.

A beam source, initially in air, are shown incident on a sphere of water.

Change the wavelength of light by moving the slider.

Use the slider to change the color of the light (by changing the frequency).

As you move the slider to the right, does the frequency of light increase or decrease?

Does the frequency increase or decrease (look up the frequencies of different colors in your book if you need to)?

Where does the red light converge? Where does the blue light converge?

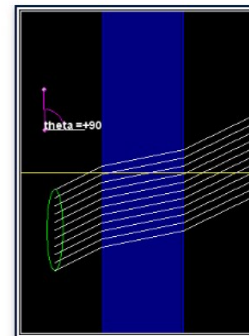
If the index of refraction of the circular blue region was 1, where would the light converge?

What would the point of convergence be? Therefore, explain why a higher index of refraction results in a convergence point closer to the sphere.

Does the convergence point move closer to the sphere as the index of refraction increases?

For which color light, then, is the index of refraction higher? For which color is it lower?

### Problem 34.1: Find index of refraction, two mediums

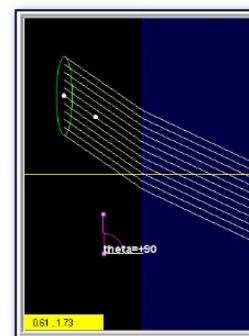


Use a JavaScript-enabled browser to open and run this Problem.

A beam of parallel rays is shown passing through a medium surrounded by air. Both the position of the source and the angle of the source rays can be adjusted by click-dragging the circular hotspots. You can move the pink protractor around and use it to measure angles (**position is given in meters and angle is given in degrees**).

- What is the index of refraction of the inner medium?
- What is the angle of total internal reflection for the inner medium?

### Problem 34.2: Find index of refraction, two mediums



Use a JavaScript-enabled browser to open and run this Problem.

A light beam source, in air, is incident on a substance of unknown index of refraction. You can click-drag both the position and the ray angle of the beam. You can move the pink protractor around and use it to measure angles (**position is given in meters and angle is given in degrees**). What is the unknown substance?

### Problem 34.3: Where is the image located?

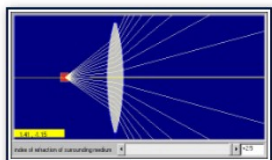


Use a JavaScript-enabled browser to open and run this Problem.

A source of light is shown in a medium. Angles can be measured by click-dragging the

protractor (**position is given in meters and angle is given in degrees**).  
 image located as seen by someone looking into the substance from the

#### 4.4: Find index of refraction of a lens



Use a JavaScript-enabled browser to open and run this Problem.

index of refraction of the lens?

#### 4.5: Size of a fish's world



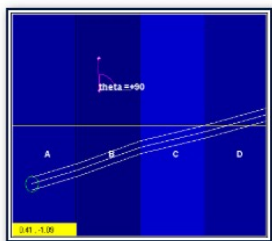
Use a JavaScript-enabled browser to open and run this Problem.

position is shown. Both the position of the source and the angle of the source  
 adjusted by click-dragging the circular hotspots. You can use the movable  
 protractor and click-drag to measure angles (**position is given in centimeters**  
**angle is given in degrees**).

radius of the fish's eye is 1 cm from the edge, how big is the circle through  
 which the fish sees the world outside the fish tank when he looks straight  
 ahead (to the right in the animation)?

Write an expression for the size of the circle through which the fish sees the  
 outside world as a function of how far away the fish is from the right edge of  
 the tank.

#### 4.6: Rank the indices of refraction

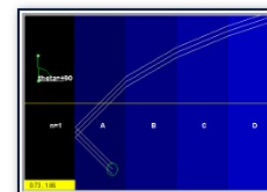


Use a JavaScript-enabled browser to open and run this Problem.

Rank the regions from smallest index of refraction to largest. You can change the angle  
 of the beam by clicking on the beam source and then click-dragging its hotspot. You

can use the movable pink protractor and click-drag to measure angles (**angle is given  
 in degrees**).

#### Problem 34.7: Total internal reflection

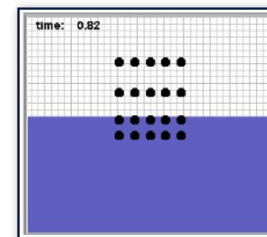


Use a JavaScript-enabled browser to open and run this Problem.

Four materials are next to each other, and the change in the index of refraction from  
 one to the next is the same. (In other words, if the index of refraction of region A is 1.5  
 AND the index of refraction of region B is 2, then the index of refraction in region C is  
 2.5, and so forth.) You can move the beam source, but you cannot change the angle of  
 the light. You can use the movable green protractor and click-drag to measure angles  
**(angle is given in degrees)**.

What is the index of refraction of region D? Explain your observations as you drag the  
 source through each of the different materials. (Why is there total internal reflection  
 between some interfaces, but not others?)

#### Problem 34.8: Wavefronts on a medium

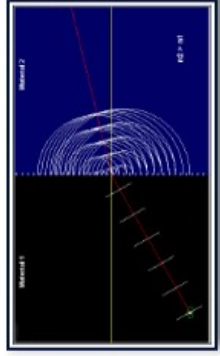


Use a JavaScript-enabled browser to open and run this Problem.

The animation models wave fronts in air entering a region of unknown index of  
 refraction. Assume the wave fronts are traveling at the speed of light (in air) before  
 entering the unknown region (**position is given in units normalized to the speed of  
 light in air**).

- Why are the wave fronts closer together in the unknown medium?
- What is the index of refraction of the unknown medium?
- In terms of the speed of light, how fast are the wave fronts traveling inside the  
 medium?

#### Problem 34.9: Huygens' principle and refraction



Use a JavaScript-enabled browser to open and run this Problem.

The animation shows a wave front passing from one medium to another. Huygens' principle is applied at the boundary between the mediums.

- What happens to the wavelength for the refracted light wave when  $n_2 > n_1$ ?
- What happens to the wavelength for the refracted light wave when  $n_2 = n_1$ ?
- What happens to the wavelength for the refracted light wave when  $n_2 < n_1$ ?
- What happens to the frequency of the refracted light wave in each of the given situations?

### Problem 34.10: Refraction and colors of light



Use a JavaScript-enabled browser to open and run this Problem.

Light rays from a beam source, initially in air, are shown incident on a piece of glass. You can change the wavelength of light by moving the slider. Which animation is correct? Explain.