Two objects with different masses are charged to the identical amounts. Then they are accelerated through the same potential of 500 Volts. That acceleration gives the

A) the heavier one more Kinetic Energy.
B) the lighter one more Kinetic Energy.
C) both objects have the same Kinetic energy.
D) More information is needed to solve this.

1. Make and use drawings. Make and use drawings. Make and use drawings.
2. Especially when vectors are involved, use ARROWS. This is especially important when Electric Fields are involved.
3. Potential gets lower when going away from a positive charge or towards a negative charge, i.e. DOWNHILL.
4. Positive charges represent HILLS and negative charges represent VALLEYS.

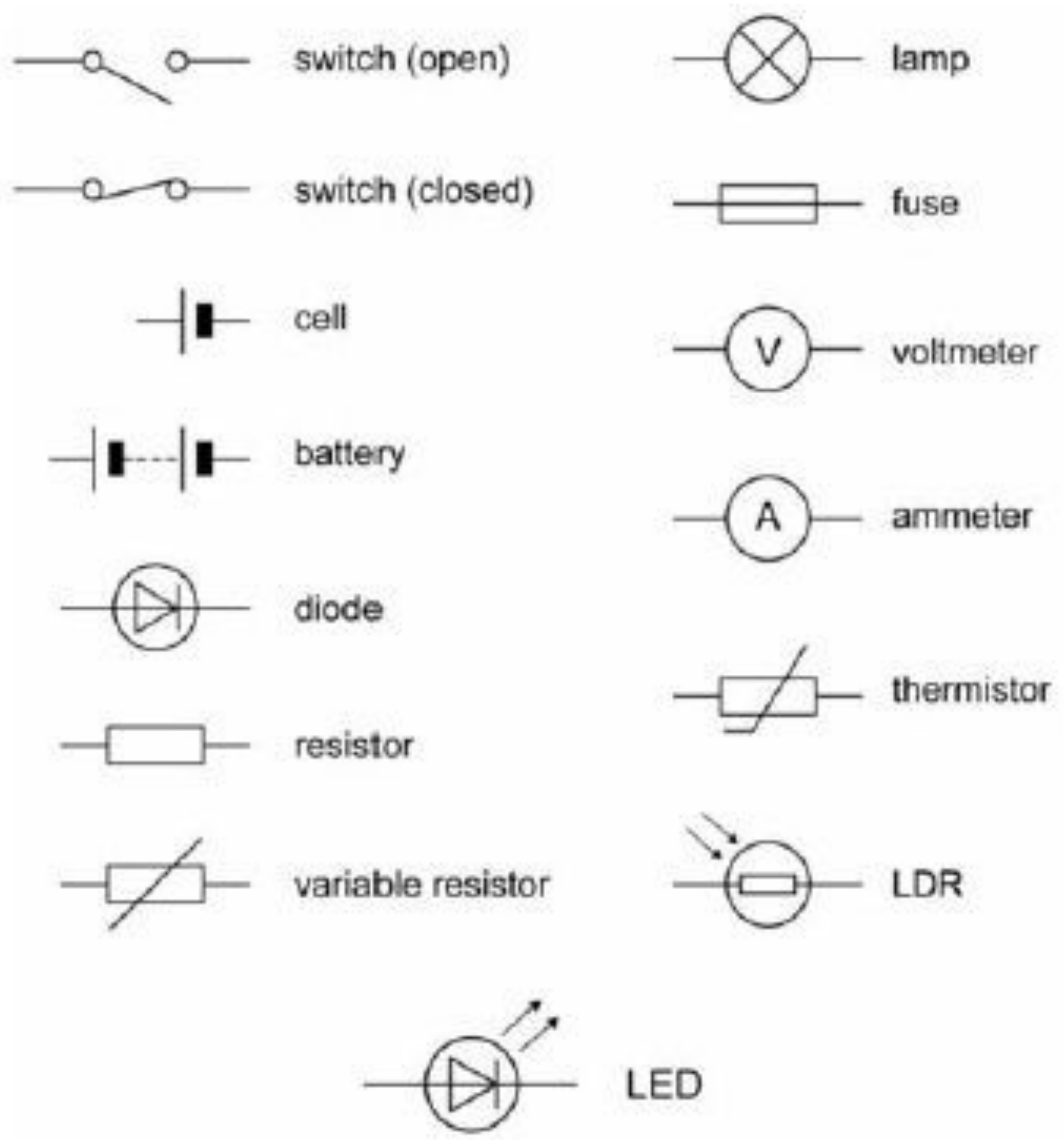
5. BUT, Potential ***Energy*** depends on the charge that is MOVING as well as the charge that created the “hill”. Thus TWO charges are now involved.

6. A *positive* charge moving downhill *loses* Potential Energy. A *negative* charge moving downhill *gains* Potential Energy.

7. Gaining Potential Energy takes positive WORK from an external source of work. Losing Potential Energy (by gaining Kinetic Energy or doing work itself) happens without external work being supplied.

8. Losing Potential Energy means either **Doing Work** or **Gaining Kinetic Energy** or **Some of Each**.

Circuit Symbols



Alessandro Giuseppe Antonio Anastasio Volta
1745 - 1827

Up to now we have worked with static electrical situations. In such cases, metals (which we have come to call conductors) cannot have Electric Fields inside them.
E fields exert forces on charges and metals have electrons not bound to any individual atom, but free to move around. They are only casually attached.

We have seen that it takes Energy to create an electric Field, and this Energy we have come to call Potential Difference or, in symbols, ΔV.

The electron was discovered in 1895. The battery was created in 1799, well before anyone knew that such things as electrons existed. But people knew that there were both attractive and repulsive forces and therefore two types of charge, which have come to be called positive and negative. (*They were originally called Vitreous and Resinous, but the names positive nd negative are easier to remember.*) But which one of these moved, or both of them moved, in a current was not known. So a choice had to be made as to what particle was moving. That choice was that Positive particles moved, so they moved in the direction of what has come to be called the Electric Field (not known in 1799) and moved from positive voltages to lower voltages. This was a sad, but unavoidable, error.

It is, of course, the negative electrons that move and that from negative places to positive places, from lower to higher potential. Nonetheless, we shall follow convention, as does almost the entire world, and PRETEND that it is positive charge moving, even though we know this is not true. But it’s what everyone does so we shall also.

If we do find some source of energy to establish a potential difference inside a metal then there will be a force on the electrons free to move and they *will* move. We call the motion of electrons a **current.**

Current can be defined mathematically, as we must do, as the movement of an *amount* of charge, a change of charge, which we'll call Δq. Remember that the Greek letter for D, Delta or Δ, means the change of whatever comes after. If this amount of charge moves in a time time Δt, then we call the current

$$i = \frac{\Delta q}{\Delta t}$$

And again, the symbol Δ means the difference of two numbers, here $q_2 - q_1$. An interesting question is how long a time interval should we consider. If the current is constant, then it doesn't matter, but if it's changing in time, then of course it matters. The question is answered by the invention of the calculus, where

$$i = \frac{dq}{dt}$$

Are charges used up in the production of light in a light bulb?

A) Yes, charge is used up. Charges moving through the filament produce "friction," get lost, which heats up the filament and produces light.

B) Yes, charge is used up. Charges are emitted as photons and are lost.

C) Yes, charge is used up. Charges are absorbed by the filament and are lost.

D) No, charge is conserved. Charges are simply converted to another form such as heat and light.

E) No, charge is conserved. Charges moving through the filament produce "friction" which heats up the filament and produces light.

Why do the lights in your home come on almost instantaneously when you turn on the switch?

A) When the circuit is completed, there is a rapid rearrangement of surface charges in the circuit.

B) Charges store energy. When the circuit is completed, the energy is released.

C) Charges in the wire travel very fast.

D) The circuits in a home are wired in parallel. Thus, a current is already flowing.

E) Charges in the wire are like marbles in a tube. When the circuit is completed, the charges push each other through the wire.

It takes Energy to move charges and this energy is provided by the battery. The battery maintains a Potential Difference, by converting chemical energy into electrical energy. This is an Energy Source but, again unfortunately and for historical reasons, batteries are called suppliers of an electromotive force, abbreviated emf, with the symbol . This is NOT a force at all but an energy source so I shall never use the term electromotive force but only the initials emf.

Batteries supply the energy needed to create the electric field within the metal and cause a current to move, or to flow, as we say.

We are now dealing with situations the opposite of the static situations we discussed earlier.

Currents flow in metals, which we call conductors. But the chemistry (and physics) of the metal (conductor) matters for the flow of current. Some conductors contribute one electron per atom, some two. In some materials the unattached electrons can move easily, while in others, it is difficult for them to move around. So we need to account for these facts. We do so by use of the term ***resistivity*** for which we use yet another Greek letter, **r** or **rho**, **ρ**. This is unique to a particular substance and there is a fantastic variation from good conductors such as silver or copper (small resistivity) where $\rho \approx 10^{-8}$. But there are non-conductors, such as Xylene or hard rubber with huge resistivities as high as 10^{17}. There are very few physical quantities with such a huge range of differences, some 25 orders of magnitude.

Finally, we need to define one more quantity. A given metal has a unique resistivity. But each individual piece will have a size and shape and these matter as well. So we shall define a quantity called the ***Resistance***, where the resistivity and the shape all come together. We define this as

$$R = \frac{\rho L}{A}$$

In this equation R is the resistance, ρ is the resistivity, L is the length of the piece of material, and A is its cross-sectional area.

The analogy of thinking of water flow often helps with understanding electricity. This is not a trivial point.

We have the concept of Energy but also the concept of Power, Energy used per Second. And, in electricity, this is a dominant concept. In Mechanics, Energy is Force x Distance and Power = Energy/time =
Force x distance/time = Force x Velocity = Fv. The unit of Power is called the **Watt**.

In Electricity we have Voltage which is measured in Volts or in Joules/Coulomb. We also have Current, measured in Amperes or Coulombs/second. If we multiply Joules/Coulomb x Coulomb/second = Joules/Second = **Watt.**
Therefore Power P = V I = Voltage x Current.

We have defined a quantity called resistance, from the fundamental properties of a given metal, called the resistivity, combined with the geometry, the length and cross-sectional area. For many materials, we have an experimentally determined relationship between the Voltage applied across a resistor and the current that will flow through due to that energy difference. This is

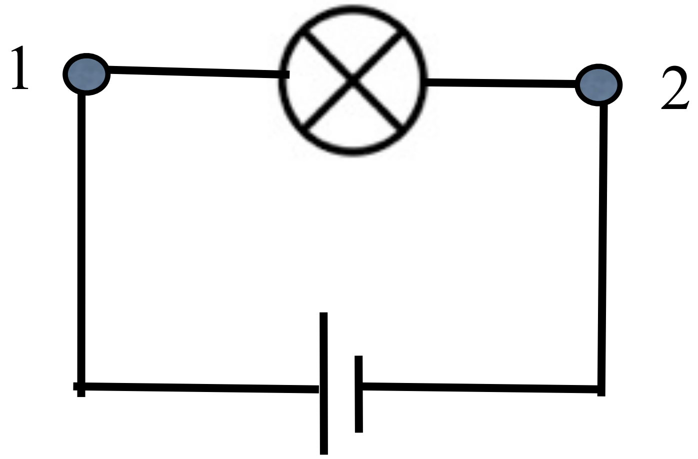
$$\mathbf{V = IR}$$

and is called Ohm’s Law, after Georg Simon Ohm, its discoverer. It is true for almost all metals and many other materials which conduct electricity.

Georg Simon Ohm 1789 - 1854

Finally, since Power is Voltage times current or P = IV and Ohm’s Law tells us that V = IR, we can write three possible equations for Power.

$$P = IV = I^2R = \frac{V^2}{R}$$



Compare the current at point 1 with the current at point 2. At which point is the current LARGEST?

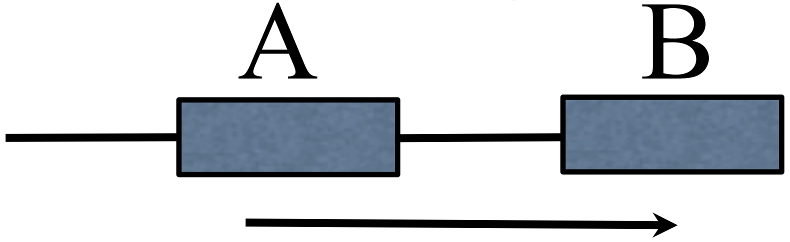
A) Point 1

B) Point 2

C) Neither, they are the same. Current travels in one direction around the circuit.

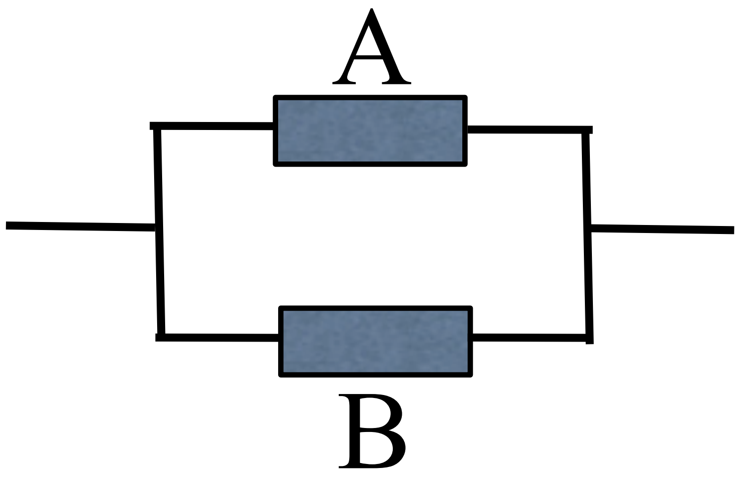
D) Neither, they are the same. Currents travel in two directions around the circuit.

Now we also need to consider circuits with resistors in them. Here are two resistors placed in series. Current will flow through the one and then directly through the other. That is, they have exactly the same currents. There is nowhere else for current to go.



$$V_{total} = V_A + V_B = i_A R_A + i_B R_B$$
$$= i(R_A + R_B)$$
$$R_{total} = R_A + R_B$$

Resistors in Series just ADD!



Here we have two Resistors in Parallel. We know then that the voltage across either must be equal, or $V_A = V_B$. The current will be different however, depending on the values of the resistors. Low value resistors have more current (easier to pass through) than high value. Then

$$i_A = \frac{V_A}{R_A}; i_B = \frac{V_B}{R_B}$$

$$i_{total} = i_A + i_B = \frac{V_A}{R_A} + \frac{V_B}{R_B} = V\left(\frac{1}{R_A} + \frac{1}{R_B}\right)$$

$$\frac{1}{R_{total}} = \frac{1}{R_A} + \frac{1}{R_B}$$

Resistors in Parallel add in their inverses!!

How does the power delivered to resistor A change when the identical value resistor B is added to the circuit? The power delivered to resistor A _____.

A) Quadruples (4 times)
B) Doubles
C) Stays the same
D) Is reduced by half
E) Is reduced to one quarter (1/4)