Physics PreLab 212-2

Energy and Work for a Conservative Force

Name ______________________________

Section ____________ **Date** ________

The Concept of Fields

Gravitational or electrical *fields* are often used to understand the forces on masses or charges. In any region of space, we can draw so-called *field lines* to represent which way the force would point if we introduced a "test object" into the picture.

On the left side of Figure 1, a massive object creates, and is surrounded by, a gravitational field $\boldsymbol{G}$. In the vicinity of this object is a "test mass." This situation is analogous to a satellite near the earth, where the satellite represents the test mass and the earth is the central massive object. While the gravitational field $\boldsymbol{G}$ does not immediately tell us the force on the test mass or satellite, it does tell us the force *per unit mass,* or $\boldsymbol{F}/m$, for any test mass we might choose. Additionally, at each point in space the gravitational field has direction, as illustrated by the arrows.

The same reasoning applies to electrical charges, except that they can either attract or repel a "test charge." We can then conceive of an electric field $\boldsymbol{E}$ that describes the force per unit charge, or $\boldsymbol{F}/q$, for any test charge as shown on the right in Figure 1. Again, notice the direction of the field. If set free, the positive test charge shown in Figure 1 would immediately begin to move in the direction of the field $\boldsymbol{E}$, along a *field line*. If the test charge were negative, of course, it would experience an electrical force in the opposite direction. The following convention has been adopted:

- The direction of an electric field at a given point is defined as the direction of the force a positive test charge would experience if placed at that point.

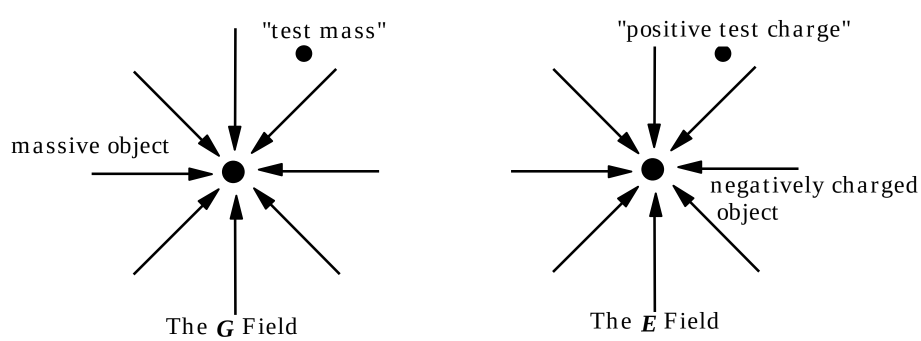
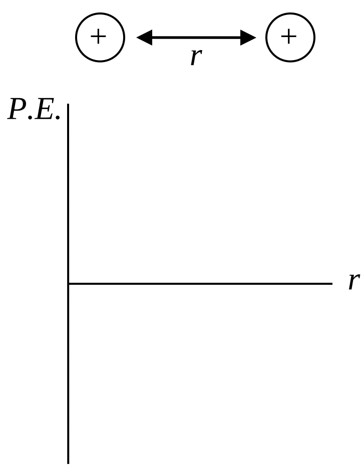


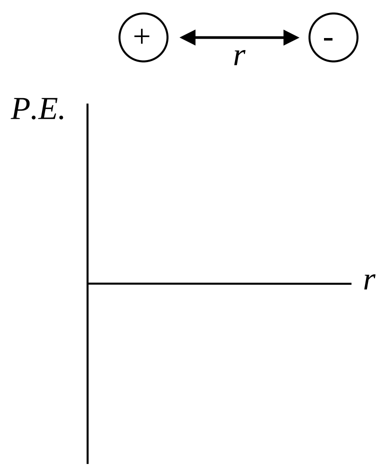
Figure 1. A comparison of G and E fields

Q1[10'] Draw an arrow on the "test mass" and on the "positive test charge" in Figure 1 to indicate the direction of the force on each of those objects. Explain how you found which way the arrow should point.

Q2[10'] Consider the expression for electrical potential energy in your textbook. For the gravitational field, the potential energy is higher when the distance between two interacting masses is greater. Is this also true for the electrical potential energy of two interacting charges?[2'] Why?[8']

Q3[10'] Two like or unlike point charges are separated by a distance *r*, as shown below. Assume the potential energy is zero when the charges are very far apart, and plot the potential energy vs. *r* for each case from *r*=0 to a very large *r*.





Work, Potential Energy, and Electric Potential

The electromagnetic forces that hold atoms together and the gravitational force that keeps planets in their orbits are "$1/r^2$ forces." Inverse square-law forces are members of a class of forces known as *conservative* forces, all of which have the following characteristic:

- The work done by a conservative force acting on an object that is moved from one point to another depends *only* on the initial and final positions of the object, *not* on the path between the two points.

Work is done on an object when a force acts upon the object over a distance. Mathematically, work is defined as the projection of the force in the direction of the object's motion multiplied by the change in displacement of the object. The summation of these terms over a path from the object's initial position to its final position gives the total work done by the force on the object over the whole path length. The equation for work is

$$W = \int \mathbf{F} \bullet \mathbf{ds} = \int \mathrm{F} \cos\theta \, \mathrm{ds} \qquad \text{(Eq. 1)}$$

where the force vector ***F*** is along the direction of motion, and d***s*** is the displacement along the path.

Consider uniform gravitational and electrical fields as depicted in Figure 2. An object starting somewhere at the top can travel to the bottom following one of many different possible paths; we have illustrated two. Since the forces are conservative, the work done by the respective fields is the same no matter what path is taken.

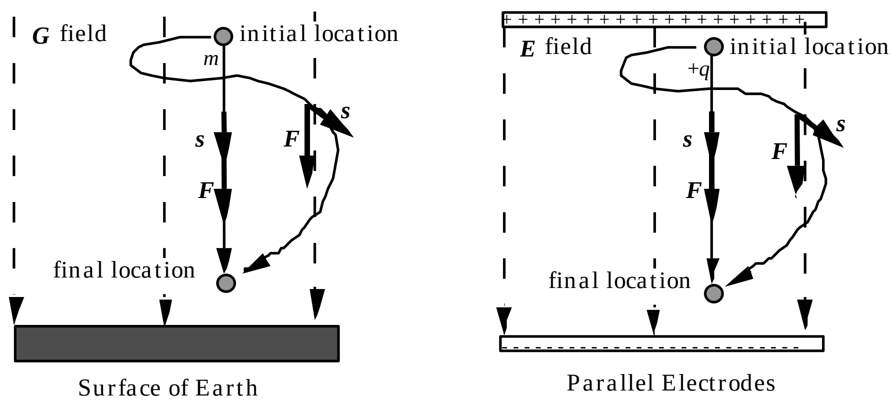


Figure 2. Work done in gravitational and electrical fields

The path independence makes it possible to define a *potential energy* for either object in Figure 2, which depends *only* on the object's location. The potential energy is a measure of how much work the field does on the object when it is brought from a standard position. In the case of the gravitational field, for example, the potential energy is large when the object is high above the earth and has a long way to fall. As the object drops, the field is performing work on it, and its potential energy decreases accordingly. To put it mathematically, the work W_{cons} done by the conservative force is related to the potential energy by

$$W_{cons} = U_i - U_f = -\Delta U \qquad \text{(Eq. 2)}$$

Suppose we reverse the situation by having us do the work - that is, we input work *against* the force field by raising the object from the "final" location to the "initial" location as shown in Figure 2. As we raise the object, we increase its potential energy and, as shown in the above equation, the field does "negative work."

It is important to remember that one can associate a potential energy function *only* with a conservative force.

In an electric field, the force is given by the expression $\boldsymbol{F} = q\boldsymbol{E}$. Using Equations 1 and 2, one can then obtain expressions for the work done by the electric field on a charge q, and the resulting potential energy of the charge. In dealing with electric fields, it is convenient to define the *electric potential difference* ΔV as the change in electrical potential energy ΔU *per unit charge* between two points A and B, or

$$\Delta V = \frac{\Delta U}{q} = \frac{U_B}{q} - \frac{U_A}{q} = V_B - V_A \qquad \text{(Eq. 3)}$$

You can think of the electric potential difference as the work *per unit charge* that an external agent must perform to move a test charge from point A to B. The electric potential difference is also known as the *voltage difference*.

Q4[10'] Explain the difference between *electrical potential energy* and *electric potential difference*.

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Q5[10'] Batteries always have two terminals, labeled + and -. The + terminal has the *higher* electric potential. If you connected the terminals to a circuit, which way would positive charges flow in the circuit?[5'] What about negative charges?[5']

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