Mapping Electric Potential

Introduction
The electrostatic interaction can be described and quantified by considering an electric field, which creates a force on a charge $q$ immersed in that field. This is a vector model, in which an electric field is thought to consist of a vector field (i.e., a vector, the electric field, assigned to every point in a region of space). An equivalent way of thinking is to consider an electric potential, in which the electrostatic interaction is quantified as a scalar field (i.e., a scalar, or number, assigned to every point in space). That scalar is the electric potential. Formally, the two approaches are equivalent (and, as we will see, there are transformations to take you from one to the other). As a practical matter, however, there are differences. In general, it is easier to deal with scalars than with vectors (for scalars, $2+2$ is always 4, whereas for vectors, $2\pm2$ can be anything from 0 to 4). And relevant to our present context, it is easier to measure potential than to measure fields.

The electric potential is to the electric field as the gravitational potential energy is to the gravitational force, and is defined in a similar way. So, a charge $q$ placed in an electric potential field will have a potential energy given by

$$ U(x, y, z) = qV(x, y, z), \quad (1) $$

where $V$ is the value of the electric potential and $U$ is the electrical potential energy, and it is made explicit that each is generally a function of position (i.e., changes from place to place). To say that an object has more gravitational potential energy at a higher altitude is equivalent to saying that it will fall from a higher altitude to a lower one. The same is true of an electric potential. To say that a positively charged particle has more electric potential energy (or is at a higher potential) at point $A$ than at point $B$ is to say that the particle will fall toward $B$ from $A$. So electric potential is, for a charged particle, analogous to altitude for a massive (gravity-influenced) particle. Positively charged particles “fall” from higher potentials to lower potentials. But where gravity affects all masses identically (as far as we know), electric interactions affect the two classes of charge (“positive” and “negative”) oppositely. Thus, while we define electric potential so that positive charges fall “down” (to lower potential, and thus lower potential energy) the same way that we defined gravitational potential energy so that massive objects fall “down”, this necessarily means that negatively charged objects will fall “up” (to higher potential). (But note well that their negative charge will ensure that they are falling to lower potential energy).

Batteries are technological devices that create a potential difference, and thus an electric potential field. A voltmeter is a technological device that reads the potential difference between the two probes connected to it. We will use a battery to establish an electric potential field and a voltmeter to plot the potential created by the battery.

Task 1) Create the Field
The field we create will be confined to a two dimensional surface. Two metal contacts (or electrodes) in the shape of a point, circle or straight line have been painted onto the surface of a special piece of paper that will support the electric field created. You will use a lead (pronounced “leed”) to connect each terminal of the battery to one of
the metal contacts. In so doing, you will “raise” the contact to the potential of that battery terminal, thus creating a potential difference between the two electrodes and establishing an electric potential field in the space surrounding them.

**Task 2) Measure the Field**

We will measure the potential field in a particular way. We will draw a picture of the metal contacts and then draw on the same picture **equipotential lines**. As suggested by their name, these are lines along which the potential does not vary. To find them, we need something that measures potential difference. Voltmeters are designed for this very purpose. There are two methods by which one may determine equipotential lines:

A) Place one probe of the voltmeter on one of the electrodes (say the “ground” or “minus” electrode) and use the other probe to trace all points on the paper at a given voltage. (For example, place the “ground” probe of the voltmeter on the “ground” electrode, and then trace all points for which the voltmeter reads “0.5 V”. You will have then traced out the 0.5 V equipotential line).

B) Place one probe anywhere on the page and then trace out all points for which the voltmeter reads zero (i.e. no potential difference). This is a more direct method (in that you have directly traced out a line of zero potential difference), but to determine which equipotential line it is you must measure the potential difference between the “ground” electrode and the line.

After you have plotted the equipotential line, label it with the magnitude of the potential difference between it and the “ground” electrode. Plot six such lines.

**Task 3) Do it again...**

...for a different electrode configuration. That is, if your first electrode configuration was two circles, one inside the other, repeat the ordeal for two circles near one another or for a line near a circle or two lines near one another...

**Task 4) See Task 3)**

At the end of the day, you should have three pictures with electrodes and equipotential lines drawn on them.

**Conclusions**

Prepare a report based on the position and shape of the electrodes and the equipotential lines arising from them. Consider what you might have expected before hand, and how those expectations were borne out (or not!). Since the electric potential plays the role of “altitude” for charges, infer from your drawings the direction that positive charges would “fall”, and discuss the reasonableness of your inference. Given the direction that positive charges would “fall”, determine the direction of the electric field you have created. End world hunger.