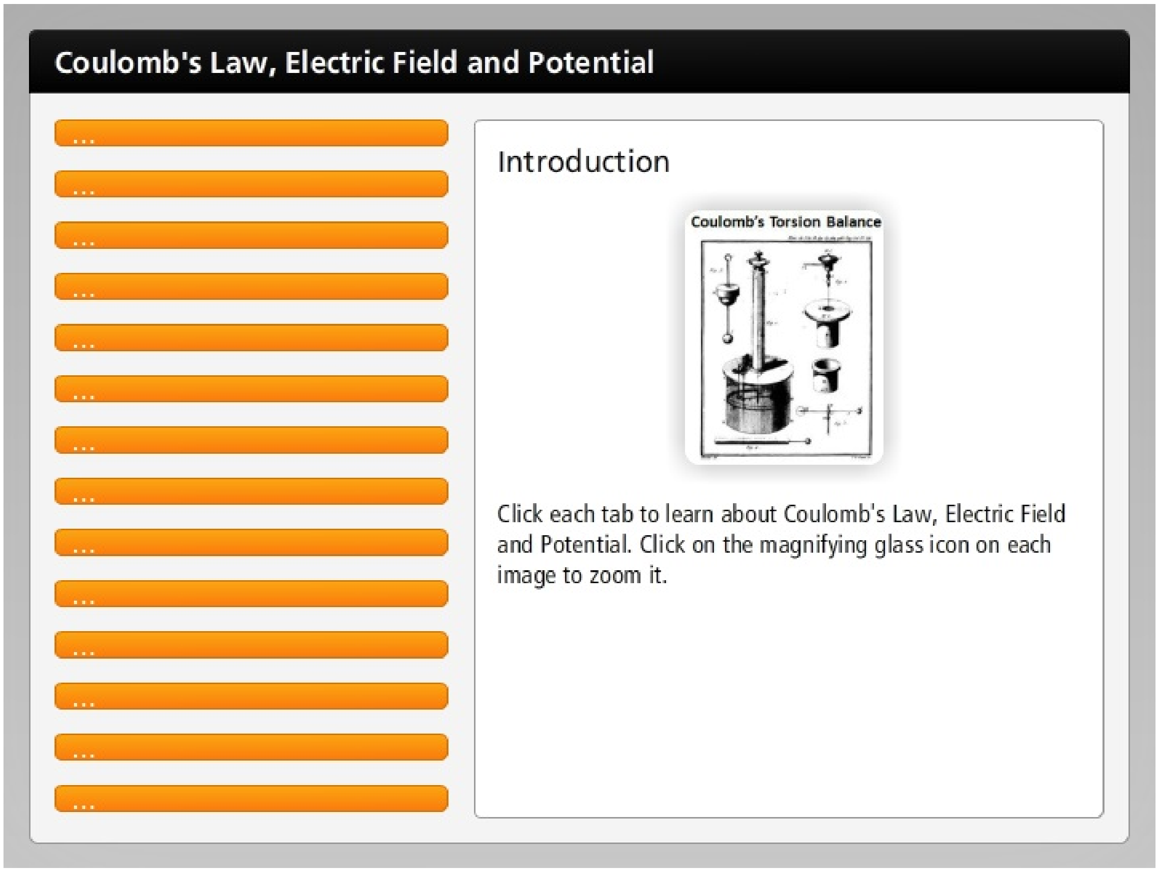
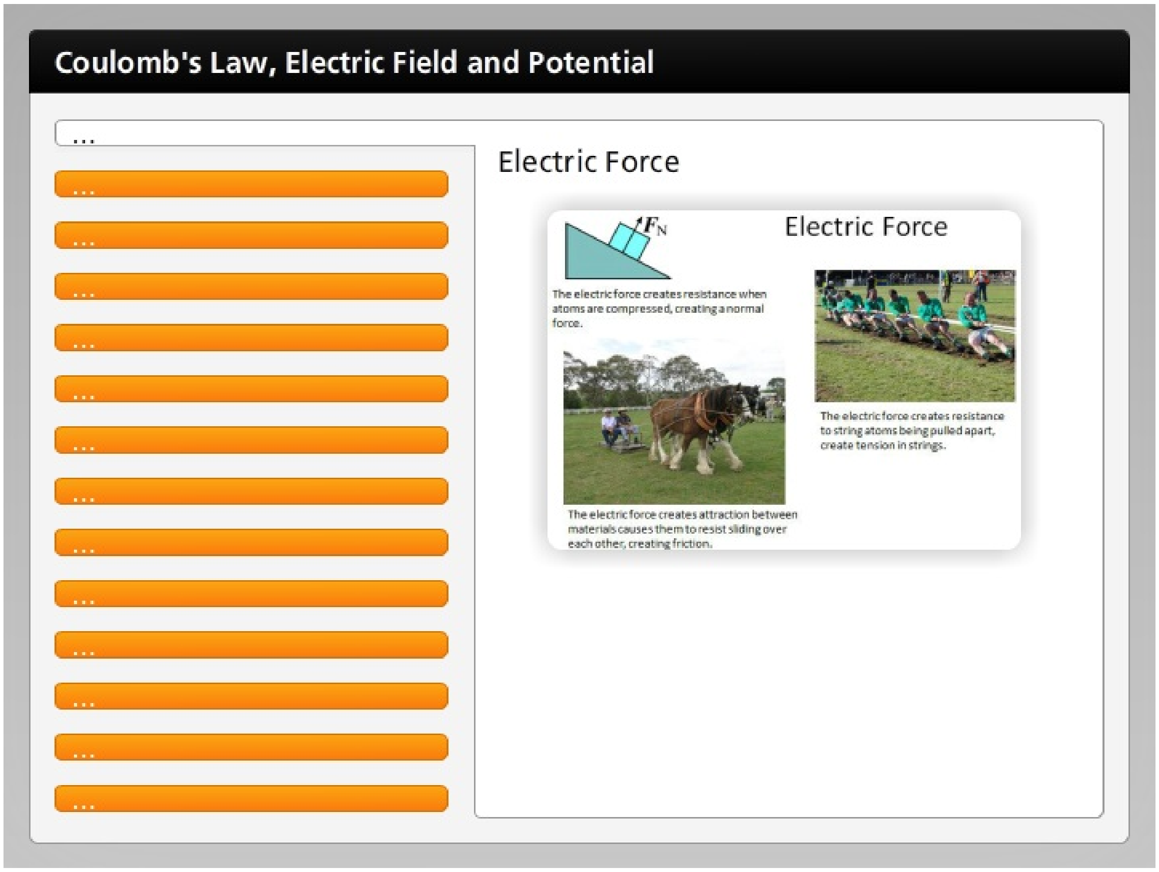
Module 7: Electricity - Currents and Circuits
Topic 2 Content: Coulomb's Law, Electric Field and Potential

Introduction



Click each tab to learn about Coulomb's Law, Electric Field and Potential. Click on the magnifying glass icon on each image to zoom it.

Electric Force



Previously, you observed that like charge repel and opposite charges attract. This electrostatic force between charges is actually the mechanism behind everyday forces that we use in Physics. For example, the electric force creates resistance to string atoms being pulled apart, create tension in strings. The electrons in each atom are attracted to the protons in the nucleus and this makes atoms resist being pulled apart. The normal force also has origins in the electrostatic force. When materials are compressed, the outer electrons in adjacent atoms repel each other, resisting compression. The frictional force is also a result of complex electrostatic forces between materials in contact. The electric force creates attraction between materials causes them to resist sliding over each other, creating friction.

All everyday forces you encounter in the study of motion: normal forces, frictional forces, and tension forces, are basically electrical. The complexity of these electrical forces prevents us from analyzing them as electrical forces, instead we just look at the result of these electrical forces on the physical system.

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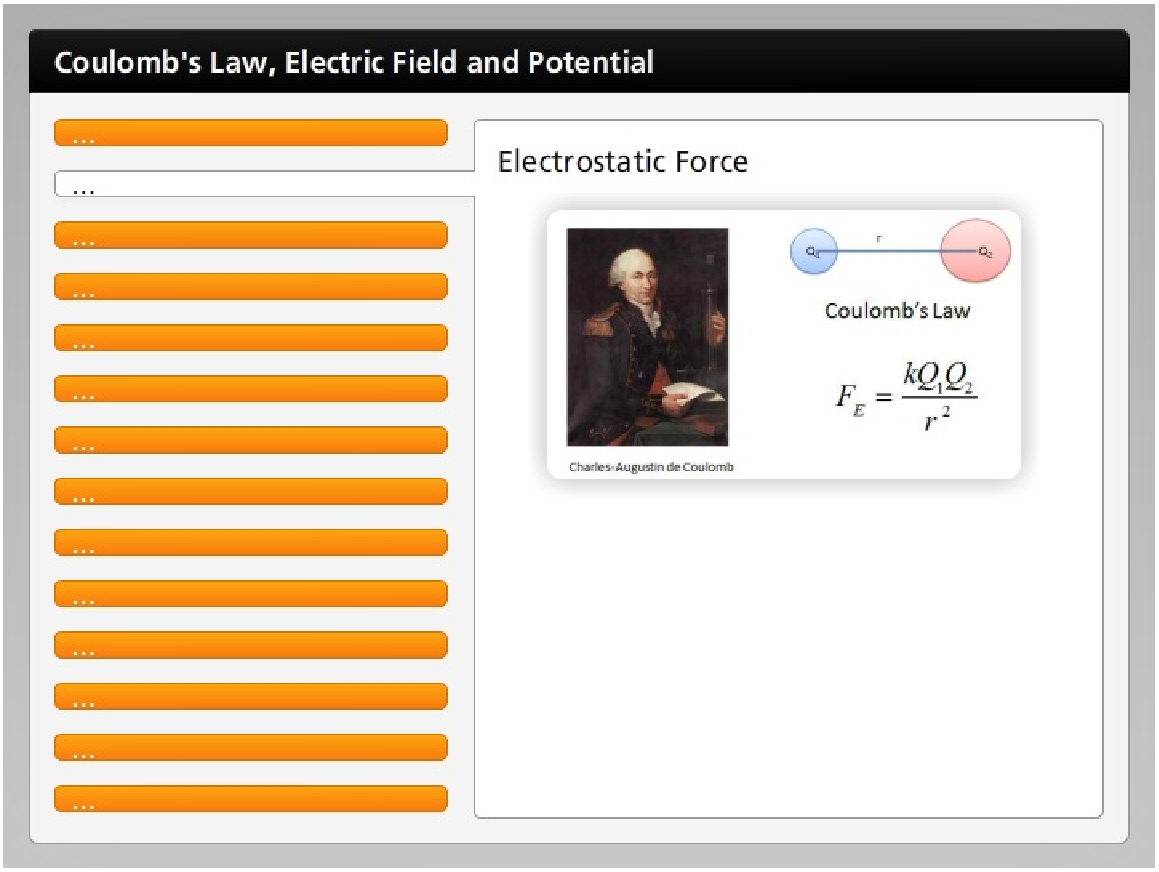
Electrostatic Force



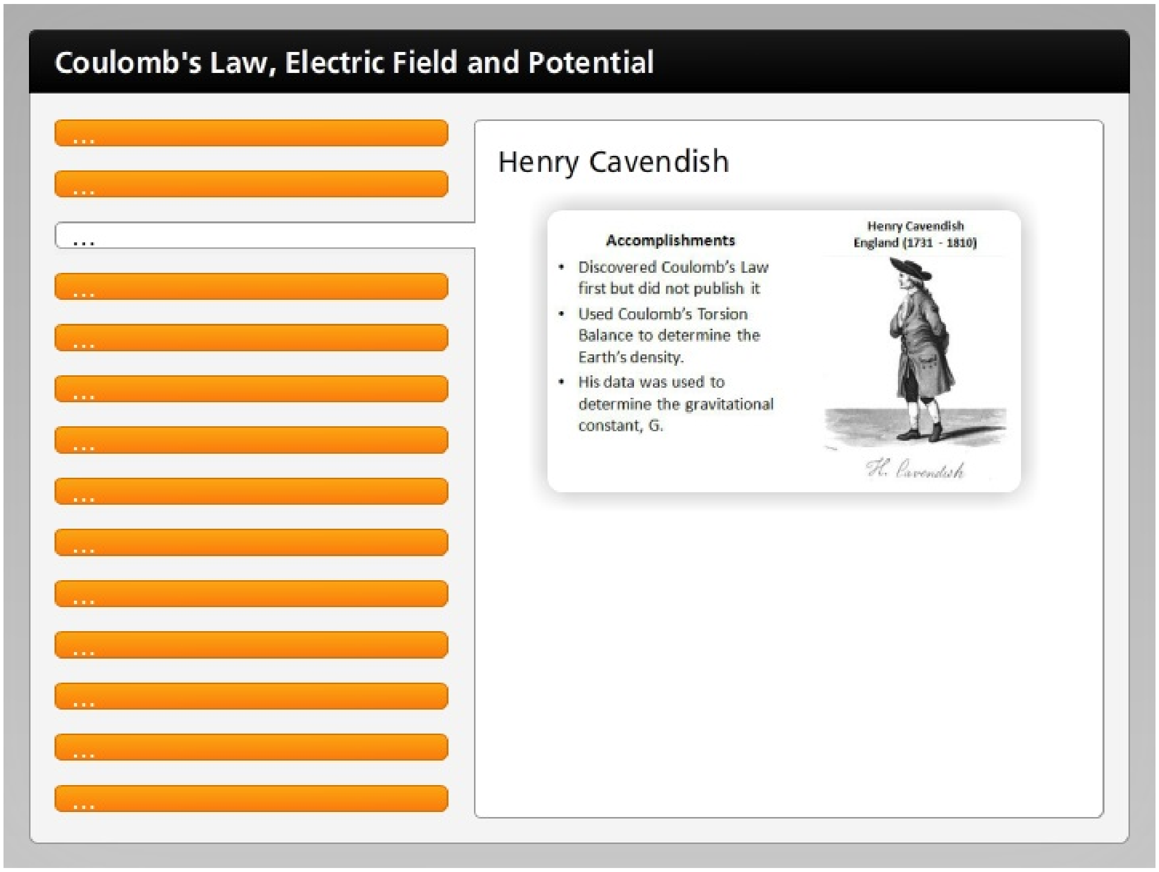
In this topic you will examine electrostatic forces between point charges. A spherical object that is uniformly charged can be treated like a point charge, where all the electric charge is at a single point in space. This simplification makes our mathematics much less complex.

The force between two point charges is described by Coulomb's Law. Coulomb's Law states that the force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them. Charles-Augustin de Coulomb is credited with the discovery of this law and the unit of charge is named after him.

The Coulomb constant, represented by the letter k, is calculated from physical constants that describe how electric forces are carried through vacuum.

As a side note, Charles-Augustin de Coulomb was a very creative scientist. He invented a clever device to measure very small forces called the Torsion Balance in 1777. Coulomb used it to measure the forces between small charges, and his results were published as Coulomb's Law in 1783.

Henry Cavendish

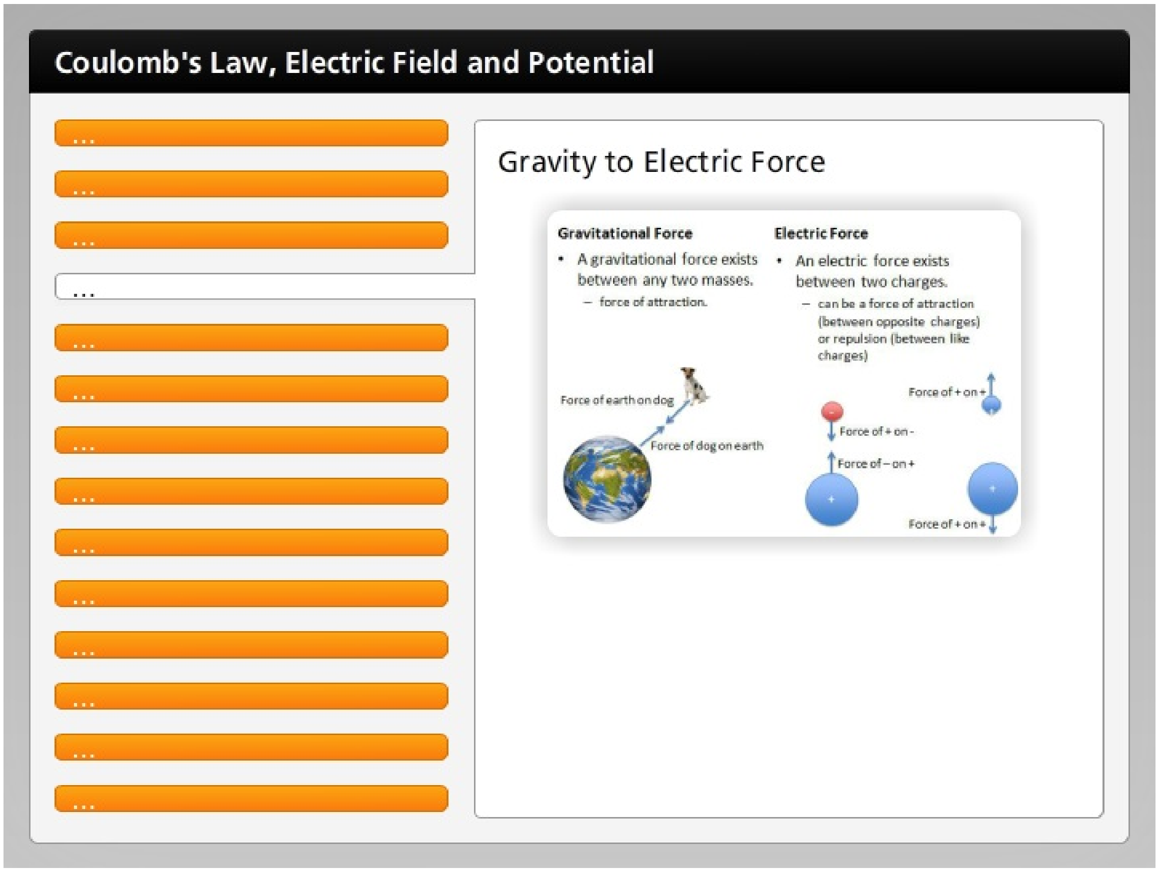


This same torsion balance was used by Henry Cavendish in 1798 to measure gravitational forces and calculate the Earth's density. This data was used to calculate the gravitational constant.

An interesting fact about Henry Cavendish is that he actually discovered the law known as Coulomb's Law first, but he did not publish his work. Therefore, Coulomb got credit for discovering it and the unit of charge was named for him. Cavendish's work was not known until James Clerk Maxwell, another famous physicist, collected and wrote about Cavendish's work one hundred years later. Cavendish was said to be painfully shy and did not have any friends outside of his family. This may be why he did not publish his work.

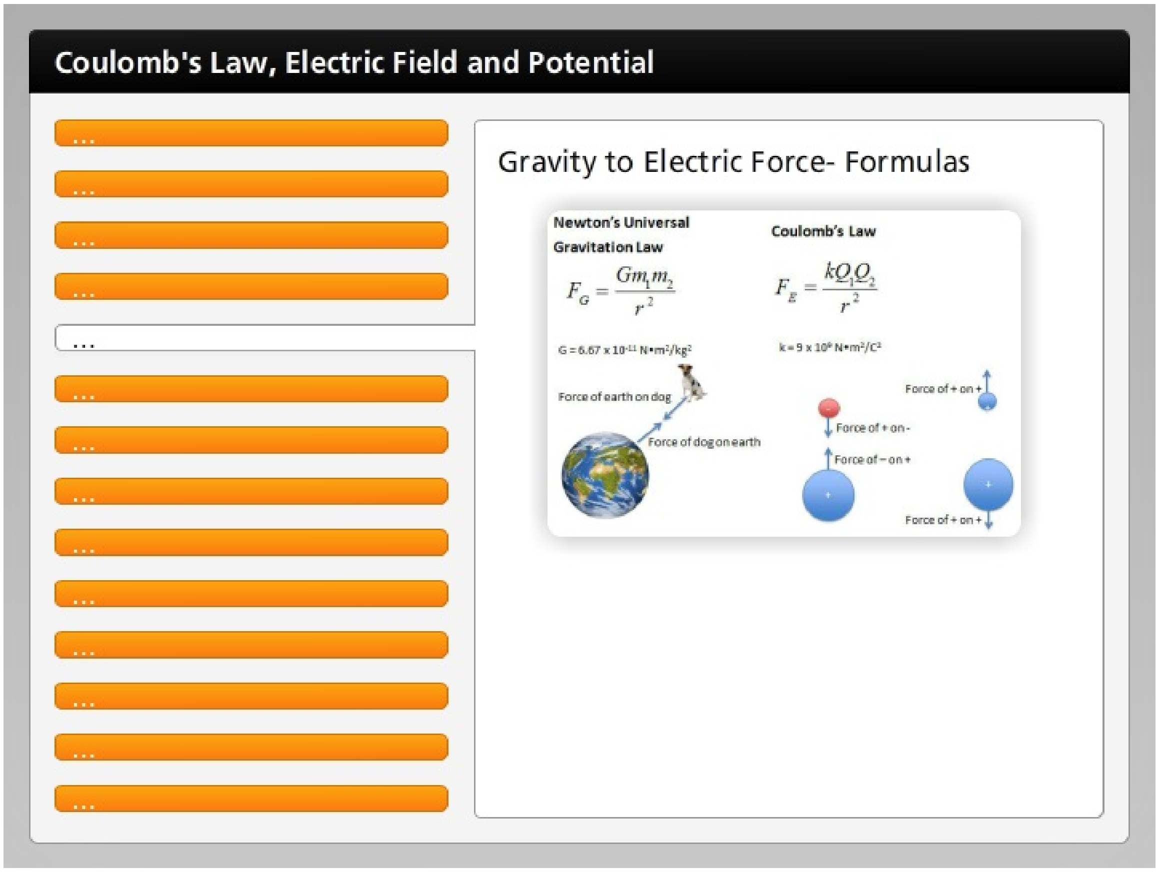
You can already see that gravitational force and electric force share some history. Let's look at the similarities and differences between these two forces.

Gravity to Electric Force



Previously you learned about the gravitational force described by Newton in his Universal Gravitation Law. Masses attract each other, and Newton's Universal Law of Gravitation describes this attractive force. Similarly, there is an electric force between charged objects. The electric force, described by Coulomb's Law can be either attractive or repulsive. Like signed charges repel and opposite signed charges attract. The electric force and the gravitational force both obey an inverse square law, that is they are both inversely proportional to the square of the distance between the objects.

Gravity to Electric Force- Formulas



If you compare the equations for Coulomb's Law and Newton's Universal Gravitation Law you should notice some similarities. The mathematical forms are very similar. Both have r squared in the denominator, this is what makes them inverse square laws. They are different because gravitational force depends on the product of the masses, while electric force depends on the product of the charges. So mass in a gravitational system is analogous to charge in an electrical system. They are also different because the constants have very different values. The coulomb constant, k, is much larger in size than the gravitation constant G. K is based on the properties of electricity in air and is theoretically determined, where G is an experimentally determined constant.

Since electrical concepts are new and you already have knowledge of gravitation, let's see how the two compare.

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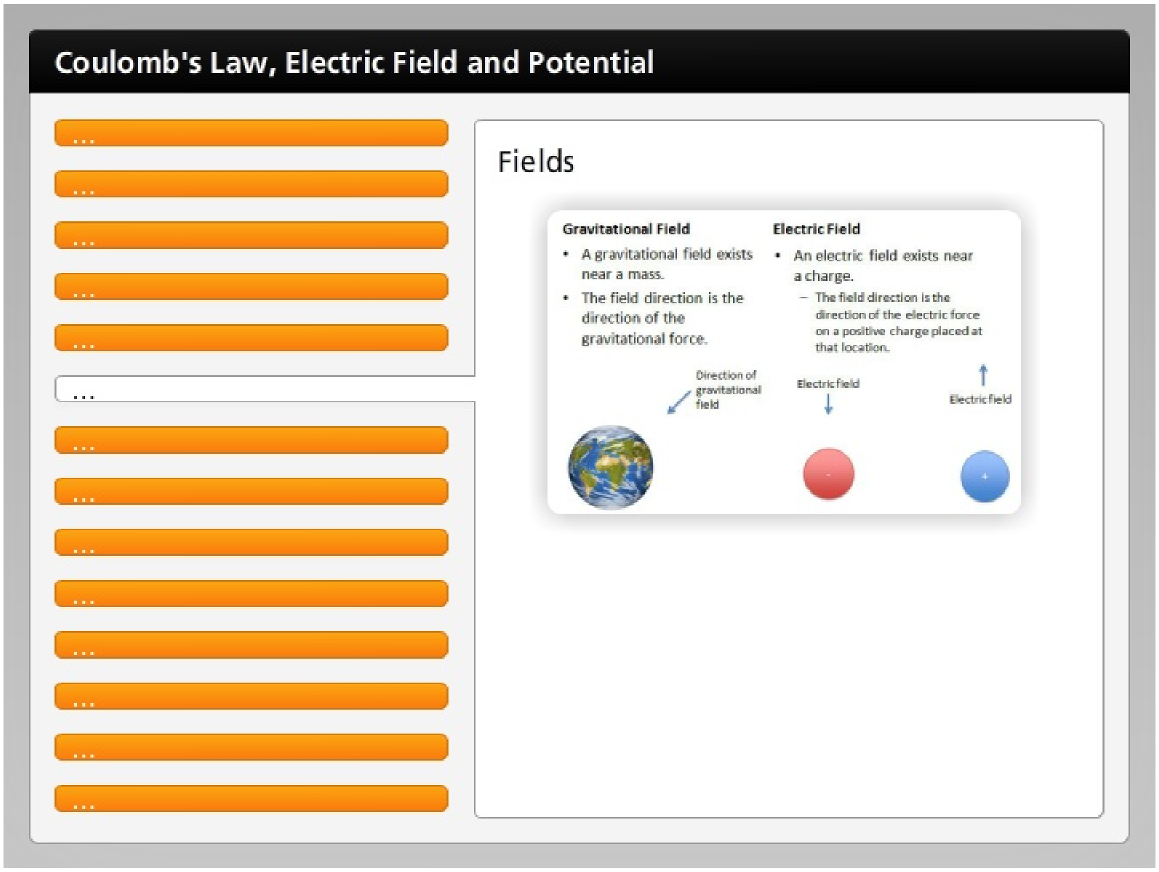
Fields

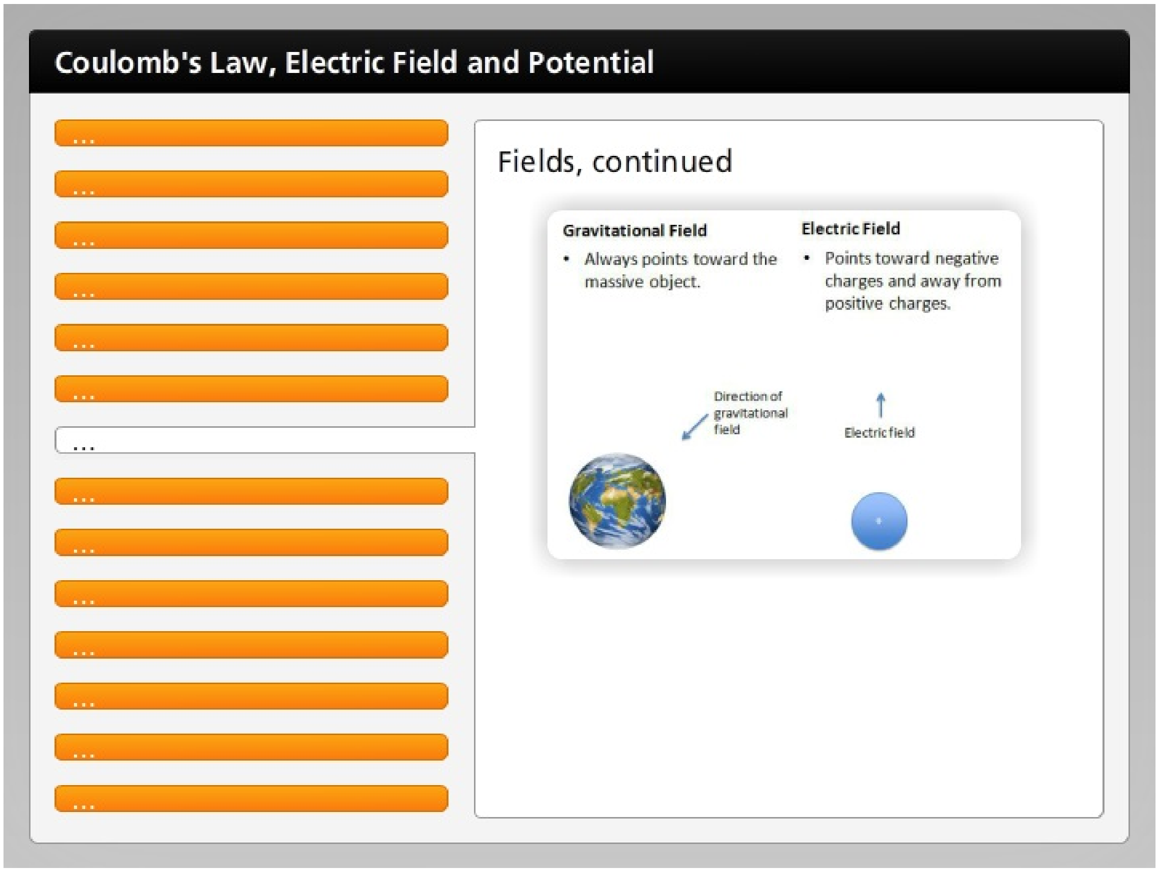


Both gravitational force and electrical force act at a distance. So massive objects have gravitational fields around them, and charged objects have electric fields around them. A field is used to describe the force that would be felt at that location. For gravitational fields we are concerned with the force per kilogram of mass. The strength of that field depends on the mass of the Earth and the distance from the Earth's center.

Near a charged object, there is an electric field. For electric fields we are concerned with the force per coulomb of charge. If you place another charged object there, it will experience a force when it interacts with the field. The strength of the electric field depends on the amount of charge creating the field and the distance from that charge.

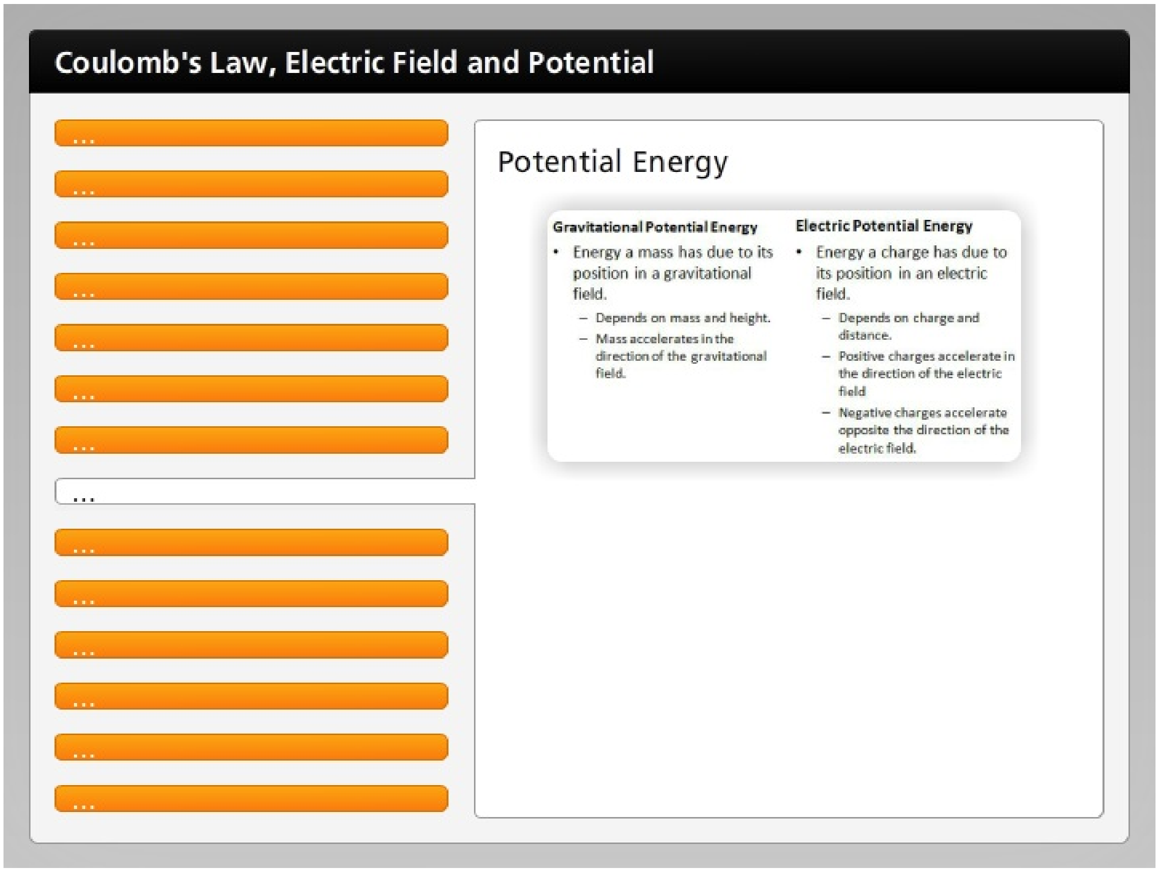
The direction of the electric field is defined by the direction of force a positive charge will experience. So for electric force, the direction of the force depends on the sign of the charge you put there. If you put a positive charge there, it will interact with the field and experience a force in the same direction as the electric field. A negative charge will interact with the field and experience a force in the opposite direction as the field.

Fields, continued



One difference between gravitational fields and electric fields is in how the direction of the field is defined. Gravitational fields always point toward the massive object. The direction of the electric field is defined by the direction of force a positive charge will experience.

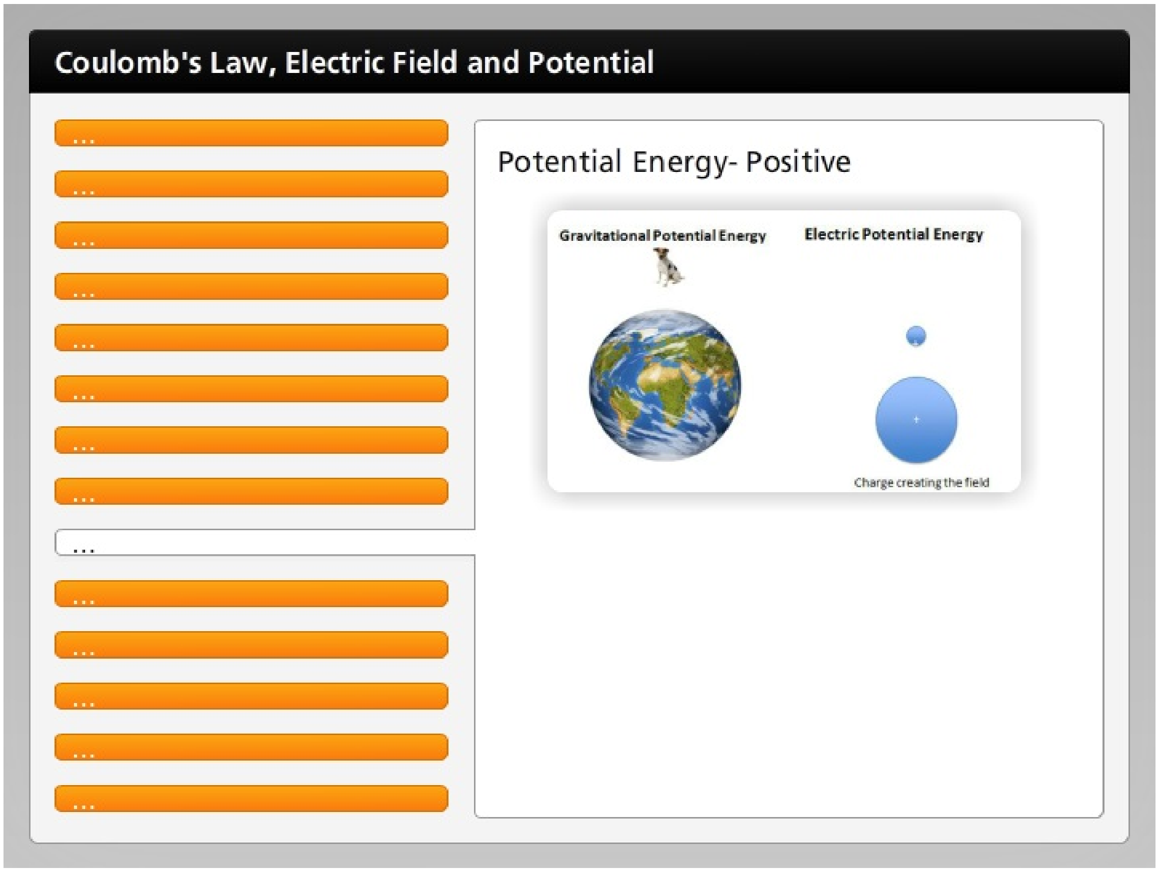
Potential Energy



The presence of a field is what creates potential energy. You have already learned about gravitational potential energy. Gravitational potential energy is energy that a mass has due to its position in a gravitational field. How much energy depends on the mass of the object and the height of the object in Earth's gravitational field.

Similarly, if you place a charge in an electric field, it will have potential energy. The potential energy of a charge in an electric field depends on the amount of charge creating the field and the distance from that charge.

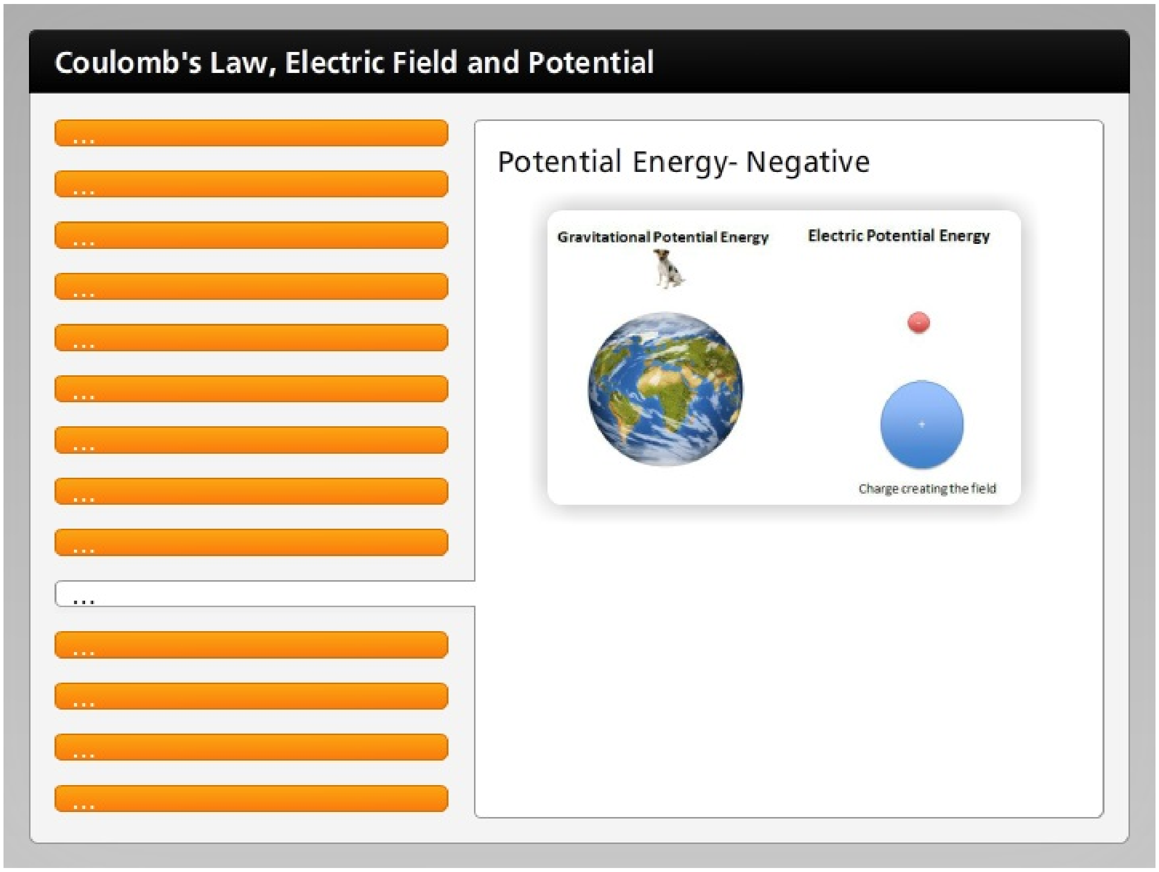
Potential Energy- Positive



The difference between these two types of fields is in how charges are acted on by fields. In a gravitational field, a mass released from rest will accelerate downward moving toward lower potential energy, in the direction of the gravitational field. If the dog is dropped, it speeds up as it falls toward the Earth's surface.

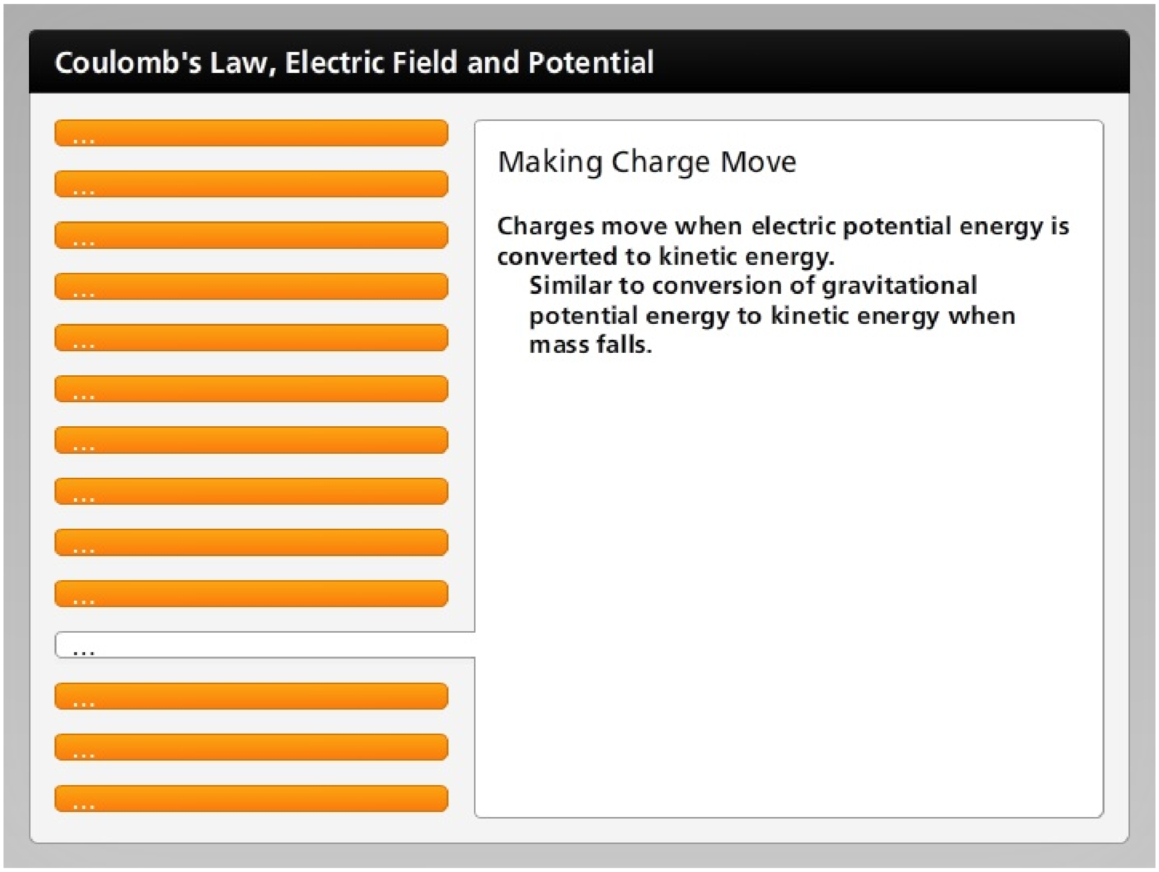
In electric fields, positive charges will experience forces in the same direction as the electric field. For example, a positive charge released in the electric field of another positive charge will move away, in the direction of the field. It is pushed away by electrostatic repulsion. As it moves away, it's potential energy decreases.

Potential Energy- Negative



But a negative charges experience forces in the opposite direction. As a negative charge accelerates opposite the direction of the electric field, its potential energy also decreases. Whenever masses or charges move in the directly they naturally would, they are moving to positions of lower potential energy.

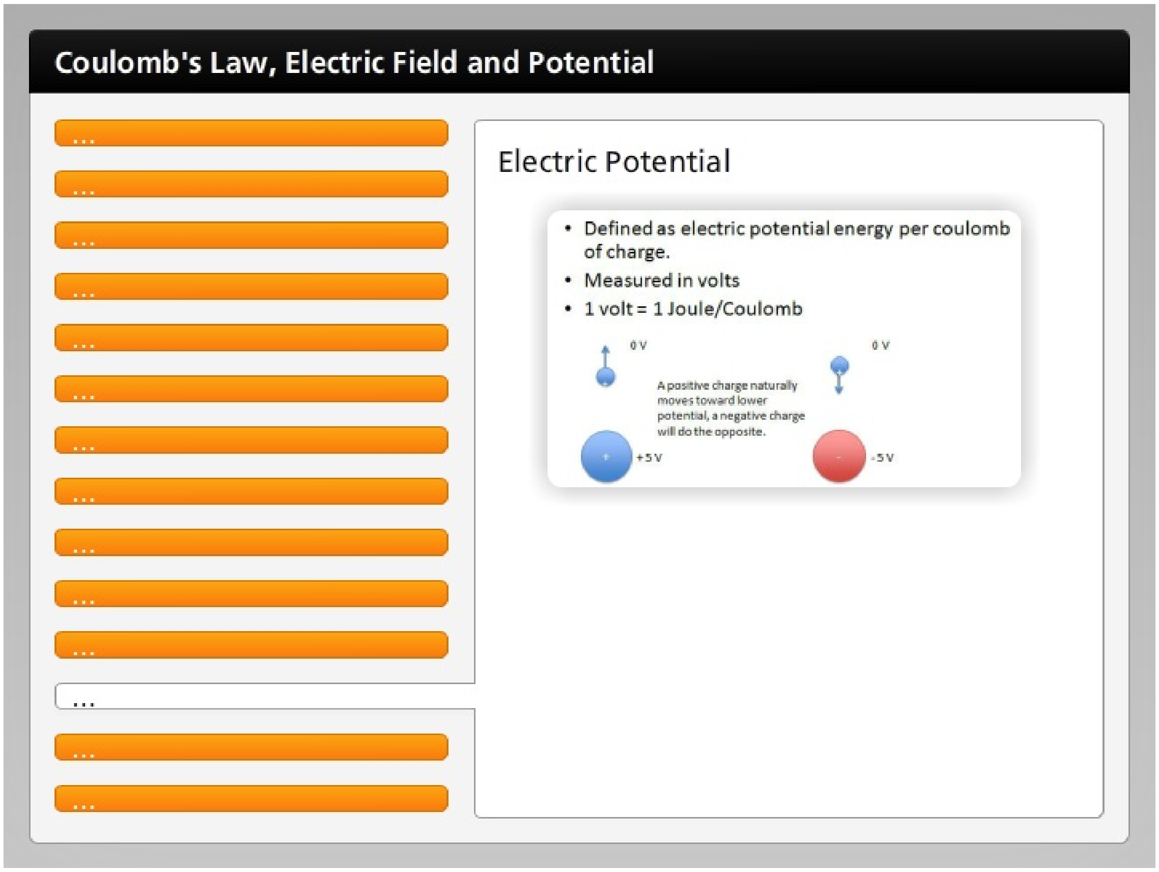
Making Charge Move



Charges move when electric potential energy is converted to kinetic energy. Similar to conversion of gravitational potential energy to kinetic energy when mass falls.

Any movement that will occur without the addition of work happens because potential energy is being used. When charges move in an electric field, electric potential energy is converted to kinetic energy. You will apply the concept of electric potential when you study circuits later on.

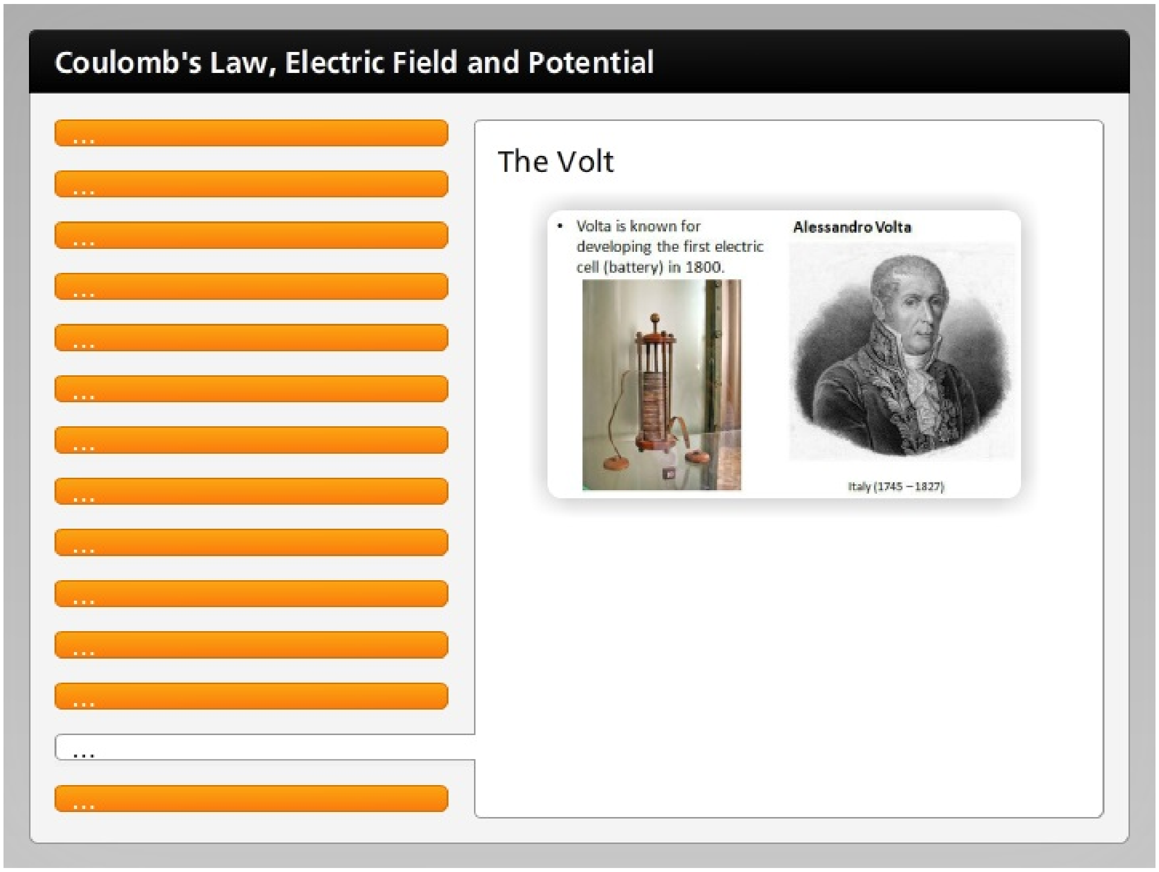
Electric Potential



Potential energy depends on charge and distance, so if you put two different charges at the same place in a field, the potential energy they have will be different also. What will be the same about the two different charges is the potential energy per coulomb of charge. This quantity is called the electric potential.

Electric potential is defined as the electric potential energy per coulomb of charge. It is measured in volts, where a volt is a joule per coulomb. Differences in electric potential (voltage) cause charges to move. Positive charges move toward lower potential, negative charges move toward higher potential.

The Volt



The volt is named after Alessandro Volta who is known for developing the first electric cell, or battery, in 1800. The battery in the picture was built by Volta. Think about the batteries that you use today. Battery technology has come a long way!

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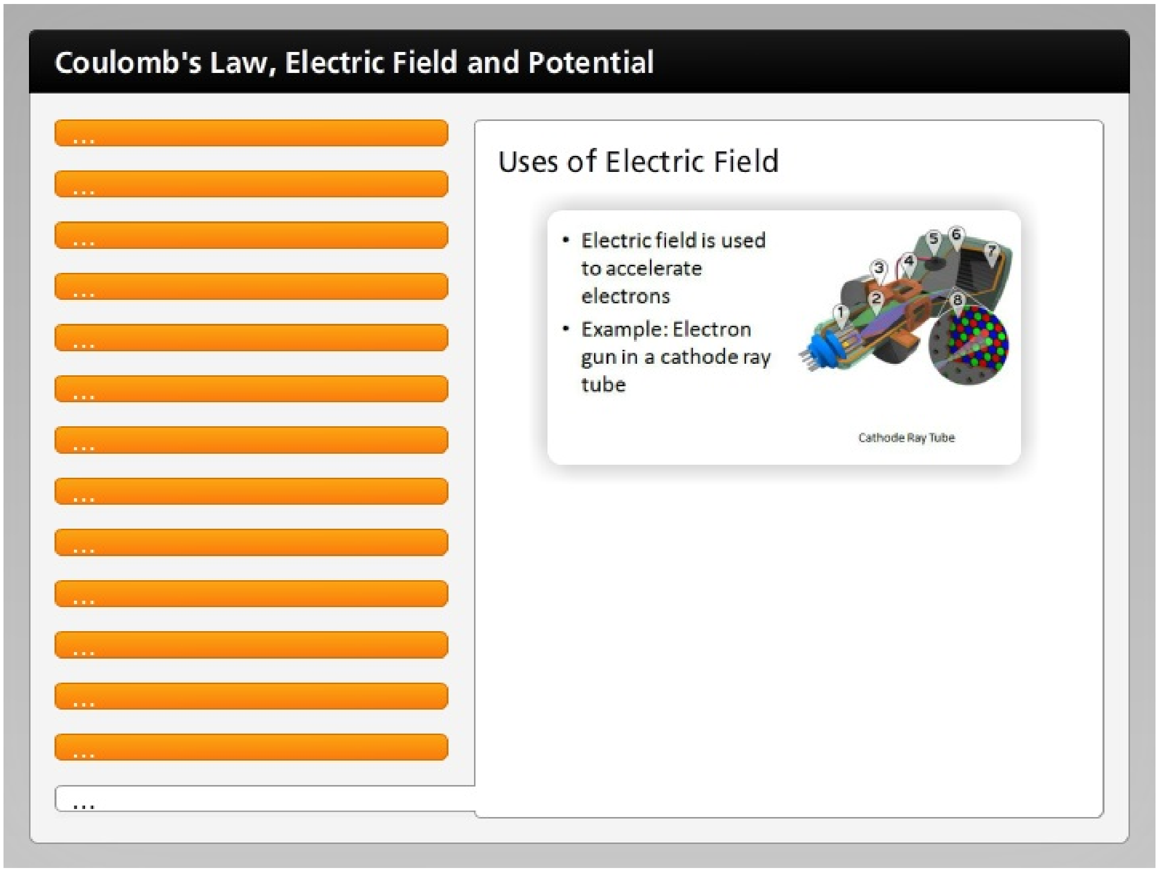
Uses of Electric Field



One application of electric field is to accelerate electrons in cathode ray tubes. Cathode ray tubes were used to create images in televisions and computer monitors before the invention of the liquid crystal display, called LCD, and the plasma display. Until 2000, CRT displays were the most common type of display for televisions, computers and many other display applications. You may have one in your house, these are the monitors and televisions with the much deeper cabinets. A CRT has an electron gun has a large electric field that converts electric potential energy to kinetic energy, accelerating the electrons toward the screen. Where the electrons strike the screen is controlled by magnetic fields. When electrons strike the screen, colored light is seen. In this diagram of a cathode ray tube, label one identifies the electron guns in this device.

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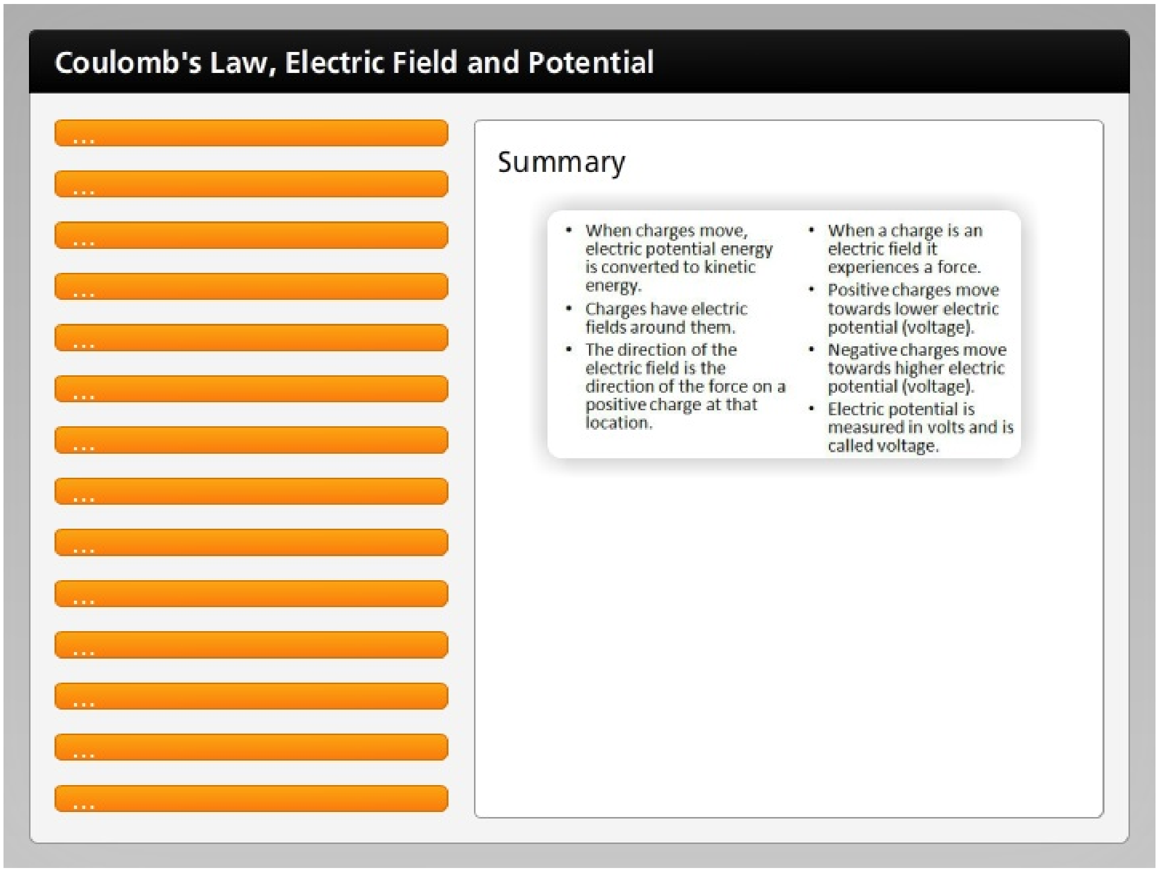
Summary



In summary:

- When charges move, electric potential energy is converted to kinetic energy.
- Charges have electric fields around them.
- The direction of the electric field is the direction of the force on a positive charge at that location.
- When a charge is an electric field it experiences a force.
- Positive charges move towards lower electric potential (voltage).
- Negative charges move towards higher electric potential (voltage).
- Electric potential is measured in volts and is called voltage.