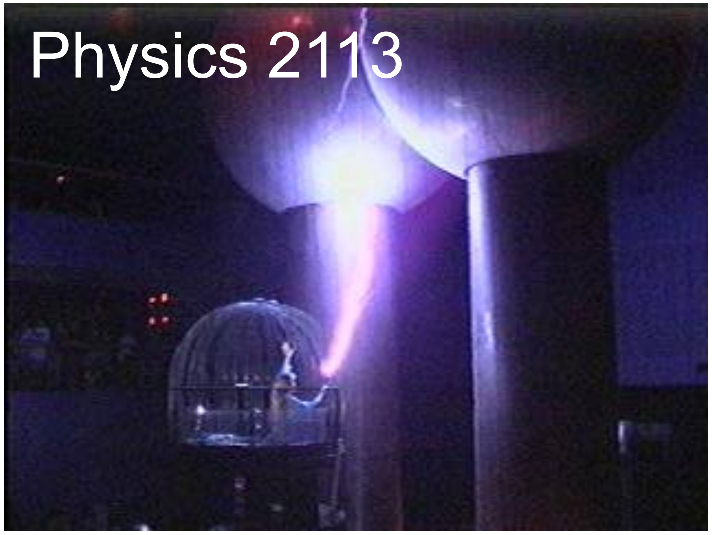
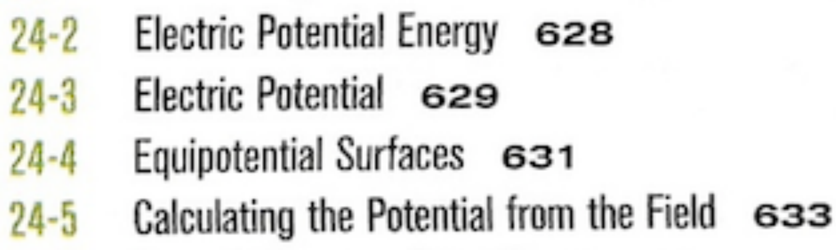



Alessandro Volta
(1745-1827)

# Physics 2113
# Lecture 11: MON 22 SEP

## CH24: Electric Potential



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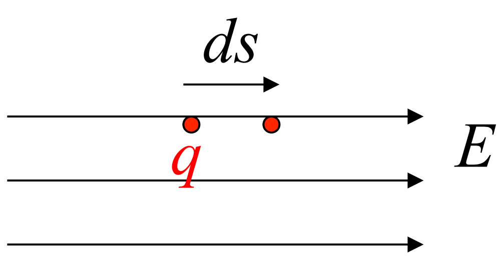
Michael Faraday
(1791–1867)

## Potential:

Reminder: In physics, the word potential refers to the ability to do work. Work refers to force times distance. The work done on a system is equal to the change in its potential energy.

Consider a charge in a constant electric field, which moves an infinitesimal distance *ds*.




Work

$$dW = \vec{F}\cdot d\vec{s} = q\vec{E}\cdot d\vec{s} = -dU$$

Change in potential energy

Finite amount: $-\Delta \mathrm{W} = \mathrm{U}_f - U_i = -q \int_{\text{Path}} \vec{E}\cdot d\vec{s}$

Electrostatic forces are conservative:

- *U* is only a function of position.
- *ΔU* independent of path. Therefore *ΔU=0* along a closed circuit.

## Definition of electric potential:

Potential energy of a system per unit charge $V = \dfrac{U}{q}$

## Units… Units...

$$V_f - V_i = \frac{U_f - U_i}{q} = -\int_i^f \vec{E}\cdot d\vec{s}$$

$$\boxed{\text{Units: } [\mathrm{V}] = \frac{\text{Joule}}{\text{Coulomb}} \equiv \text{Volt}}$$

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$$[\mathrm{Volt}] = \left[\frac{\mathrm{N}}{\mathrm{C}}\right][\mathrm{m}] \Rightarrow \left[\frac{\mathrm{N}}{\mathrm{C}}\right] = \left[\frac{\mathrm{V}}{\mathrm{m}}\right]$$

Unit most commonly used for electric fields

$$\Delta V = \frac{\Delta U}{q} \Rightarrow \Delta U = q\Delta V$$

$eV$=electron-volt, the energy that an electron acquires when placed in an electric potential of $1V$

$$1\,eV = (1.6\times 10^{-19}\,C)V = 1.6\times 10^{-19}\,J$$

Since what matters in potential energy (and therefore in electrical potential) are differences, the potential is in general defined up to a constant. One way of fixing that constant is to declare that some point in space has zero potential. Very commonly infinity is chosen as that point.

In that case we have that $$V = -\frac{W_\infty}{q}$$

Where $W_\infty$ is the work done by the electric field on a charged particle as it is brought from infinity to its current location.

If one moves a charge across a field exerting a force on it, there are two types of work done: the one by the external force and the one by the field. Their sum will be equal to the change in the kinetic energy of the charge. If the particle is stationary before and after the move, then $W_{app}=-W_{field}=q\Delta V$.

## Work and potential energy in an electric field

Electrons are continually being knocked out of air molecules in the atmosphere by cosmic-ray particles coming in from space. Once released, each electron experiences an electrostatic force $\vec{F}$ due to the electric field $\vec{E}$ that is produced in the atmosphere by charged particles already on Earth. Near Earth's surface the electric field has the magnitude $E = 150$ N/C and is directed downward. What is the change $\Delta U$ in the electric potential energy of a released electron when the electrostatic force causes it to move vertically upward through a distance $d = 520$ m (Fig. 24-1)?

**KEY IDEAS**

(1) The change $\Delta U$ in the electric potential energy of the electron is related to the work $W$ done on the electron by the electric field. Equation 24-1 ($\Delta U = -W$) gives the relation.

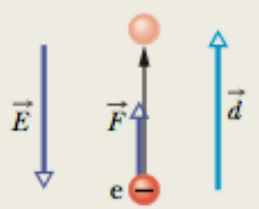



**Fig. 24-1** An electron in the atmosphere is moved upward through displacement $\vec{d}$ by an electrostatic force $\vec{F}$ due to an electric field $\vec{E}$.

(2) The work done by a constant force $\vec{F}$ on a particle undergoing a displacement $\vec{d}$ is

$$W = \vec{F} \cdot \vec{d}. \tag{24-3}$$

(3) The electrostatic force and the electric field are related by the force equation $\vec{F} = q\vec{E}$, where here $q$ is the charge of an electron ($= -1.6 \times 10^{-19}$ C).

***Calculations:*** Substituting for $\vec{F}$ in Eq. 24-3 and taking the dot product yield

$$W = q\vec{E} \cdot \vec{d} = qEd \cos \theta, \tag{24-4}$$

where $\theta$ is the angle between the directions of $\vec{E}$ and $\vec{d}$. The field $\vec{E}$ is directed downward and the displacement $\vec{d}$ is directed upward; so $\theta = 180°$. Substituting this and other data into Eq. 24-4, we find

$$W = (-1.6 \times 10^{-19}\text{ C})(150\text{ N/C})(520\text{ m}) \cos 180°$$
$$= 1.2 \times 10^{-14}\text{ J}.$$

Equation 24-1 then yields

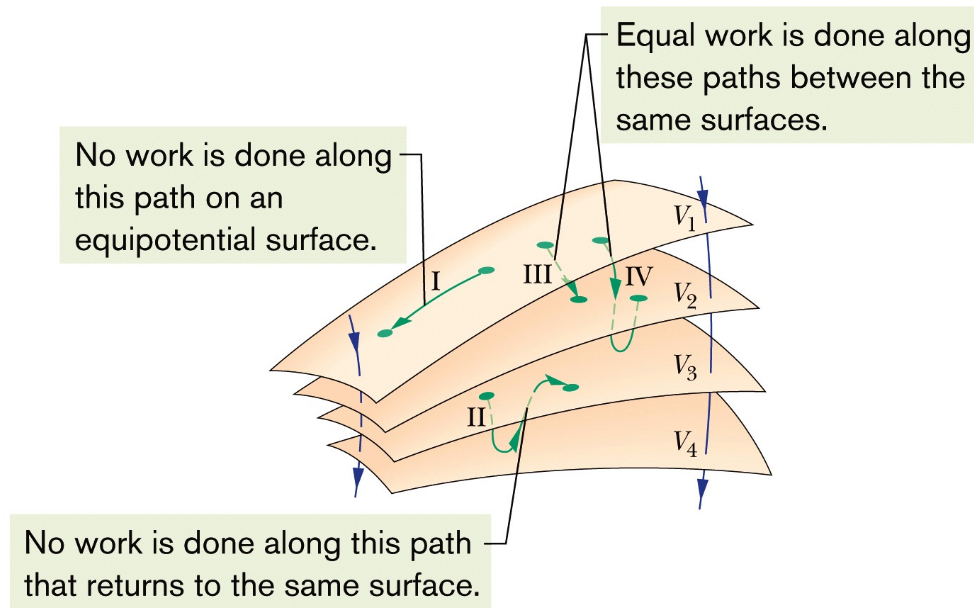
$$\Delta U = -W = -1.2 \times 10^{-14}\text{ J}. \qquad \text{(Answer)}$$

This result tells us that during the 520 m ascent, the electric potential energy of the electron *decreases* by $1.2 \times 10^{-14}$ J.

## Equipotential surfaces

Adjacent points that have the same electric potential form an **equipotential surface**, which can be either an imaginary surface or a real, physical surface.

The figure shows a family of equipotential surfaces associated with the electric field due to some distribution of charges. The work done by the electric field on a charged particle as the particle moves from one end to the other of paths **I** and **II** is zero because each of these paths begins and ends on the same equipotential surface and thus there is no net change in potential. The work done as the charged particle moves from one end to the other of paths **III** and **IV** is not zero but has the same value for both these paths because the initial and final potentials are identical for the two paths; that is, paths **III** and **IV** connect the same pair of equipotential surfaces.



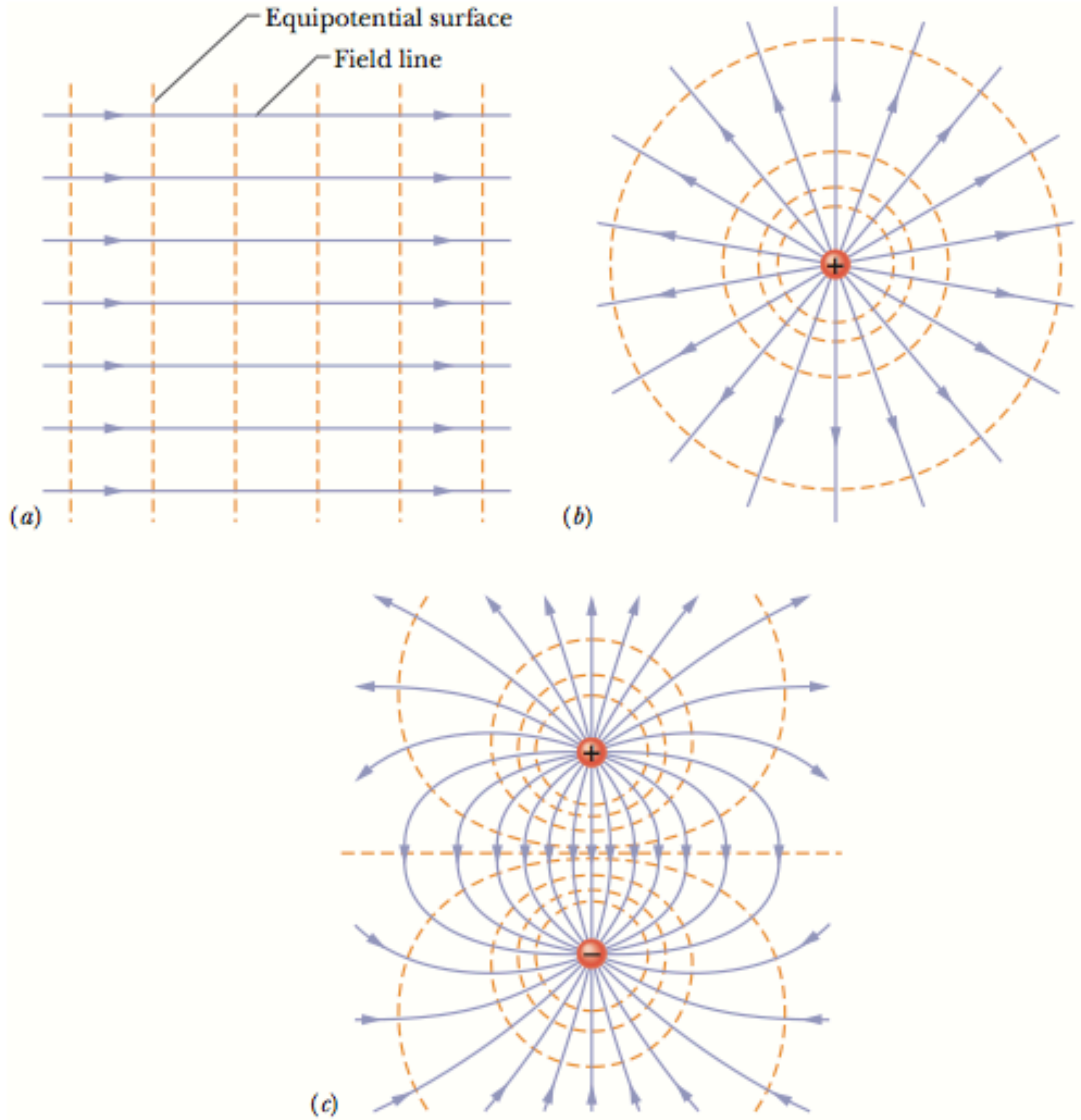
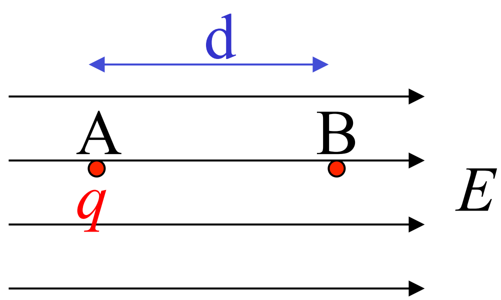



**Fig. 24-3** Electric field lines (purple) and cross sections of equipotential surfaces (gold) for (*a*) a uniform electric field, (*b*) the field due to a point charge, and (*c*) the field due to an electric dipole.

# Computing potential differences: uniform field




$$V_B - V_A = \Delta V = -\int_A^B \vec{E}\cdot d\vec{s} = -\int_A^B E\,ds = -E\int_A^B ds = -E\,d$$

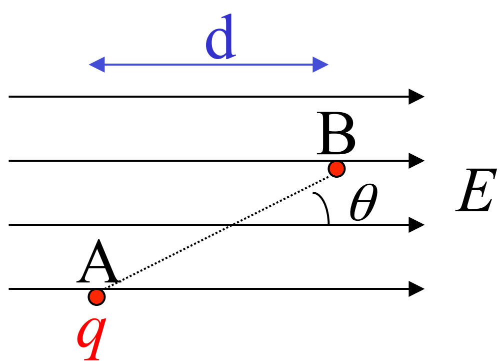
Field, separation parallel

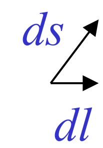
Constant field

Minus sign: $V_B < V_A$

In terms of potential energy, one has to be careful, since the sign of the difference depends on the sign of the charge.
Positive charges lose energy moving along field lines.
Negative charges gain energy moving along field lines.
(Rule: whenever a motion looks "natural", it implies losing energy!)

# Transverse motion:



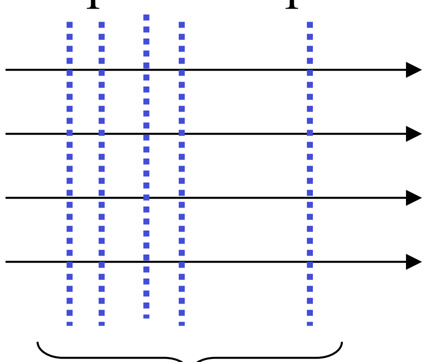




$$V_B - V_A = \Delta V = -\int_A^B \vec{E}\cdot d\vec{s} = -\int_A^B E\,ds\cos\theta = -E\int_A^B dl = -E\,d$$

Field, separation at a constant angle

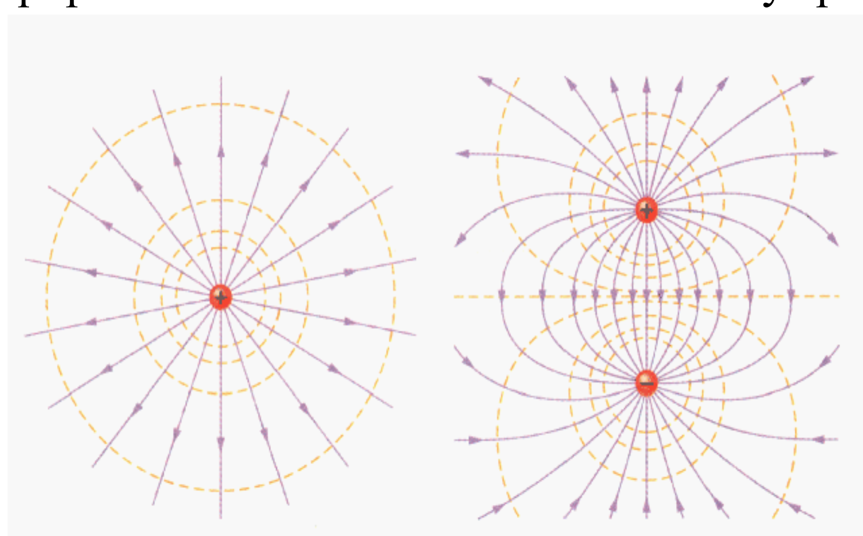
Constant field, $dl = ds\cos\theta$

All points in planes perpendicular to $E$ are at a constant potential (equipotentials).



Equipotential surfaces

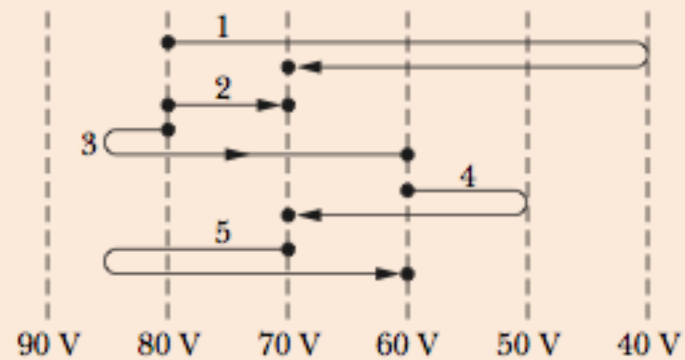
- No work is done when moving along an equipotential surface.
- Equipotential surfaces are therefore always perpendicular to the field.



Equipotentials for point charge and dipole

## CHECKPOINT 3

The figure here shows a family of parallel equipotential surfaces (in cross section) and five paths along which we shall move an electron from one surface to another. (a) What is the direction of the electric field associated with the surfaces? (b) For each path, is the work we do positive, negative, or zero? (c) Rank the paths according to the work we do, greatest first.



# Summary:

- We can characterize an electric field through the potential energy charges acquire in it.
- Potentials can be easily superposed (numbers not vectors), and have an immediate physical interpretation.