Electricity and Magnetism
Electric Potential

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Last time

- electric potential energy
- potential energy of a pair of charges
- potential energy of a configuration of many charges
- dipole in an electric field

Overview

- Electric potential
- Equipotential surfaces
- relating potenital and electric field

Electric Potential

Electric potential is a new quantity that relates the effect of a charge configuration to the potential energy that a test charge would have in that environment.

It is denoted V.

electric potential, V

the potential energy per unit charge:

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

V has a unique value at any point in an electric field.

It is characteristic only of the electric field, meaning it can be determined just from the field.

Electric Potential

Potential is potential energy per unit charge:

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

The units are Volts, V.

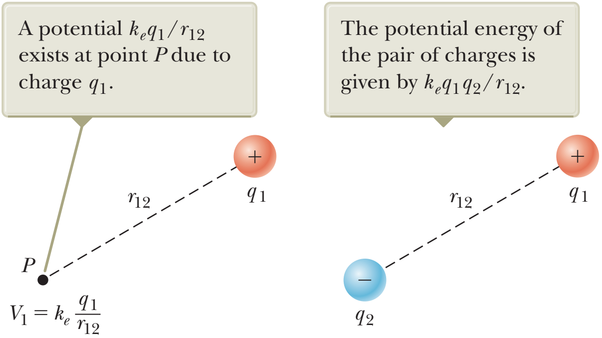
$1 \text{ V} = 1 \text{ J/C} = 1 \text{ A } \Omega = 1 \, \frac{\text{kg m}^2}{\text{A s}^3}$

Volts are also the units of **potential difference**, the change in potential: ΔV.

Electric Potential and Potential Energy

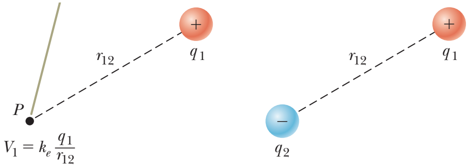
Electric potential gives the potential energy that would be associated with test charge q_0 if it were at a certain point P.

$$U_{P,q_0} = q_0 V_p$$



[1]Figure from Serway and Jewett, 9th ed.

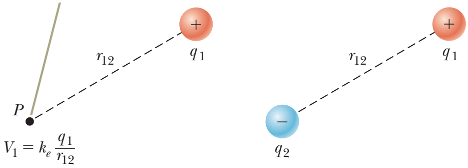
Electric Potential and Potential Energy



For a point charge q_2, its potential energy when near another point charge q_1 is

$$U = \frac{k\, q_1 q_2}{r}$$

Electric Potential and Potential Energy



For a point charge q_2, its potential energy when near another point charge q_1 is

$$U = \frac{k\, q_1 q_2}{r}$$

We say that the electric potential at point P due to q_1 is

$$V = \frac{k\, q_1}{r}$$

so that if a charge q_2 is placed there:

$$q_2 V = q_2 \left(\frac{k\, q_1}{r} \right) = U$$

gives the potential energy of the 2-charge configuration!

Electric Field and Electric Potential

Potential, V, is potential energy per unit charge:

$$U = qV$$

Electric field, $\mathbf{E}$, is force per unit charge:

$$\mathbf{F} = q\,\mathbf{E}$$

Notice the relation! Both quantities are defined so that we can predict physical quantities associated with putting a charge at a certain point.

Electric Field and Electric Potential

Table of quantities for the field and potential of a point charge Q.

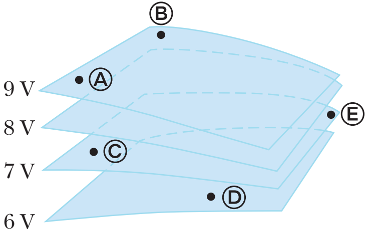
	electric field	electric potential
at point P	$E = \frac{k\,Q}{r^2}$	$V = \frac{k\,Q}{r}$
charge q_0 at P	$F_{q_0} = \frac{k\,Q\,q_0}{r^2}$	$U = \frac{k\,Q\,q_0}{r}$

Equipotential Surfaces

The fields from charges extend out in 3 dimensions.

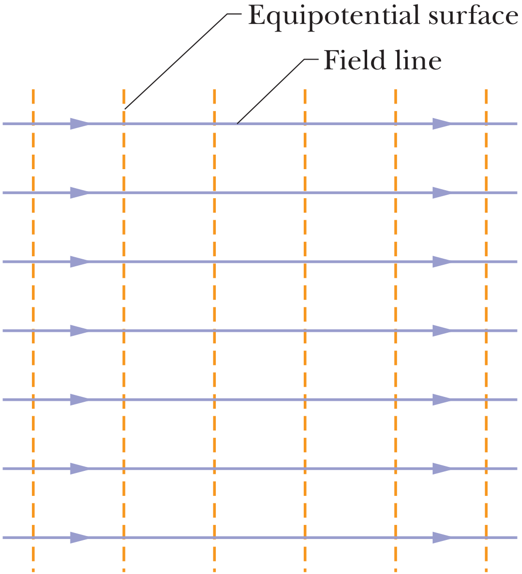
We can find 2-dimensional surfaces of constant electric potential.

These surfaces are called *equipotentials*.



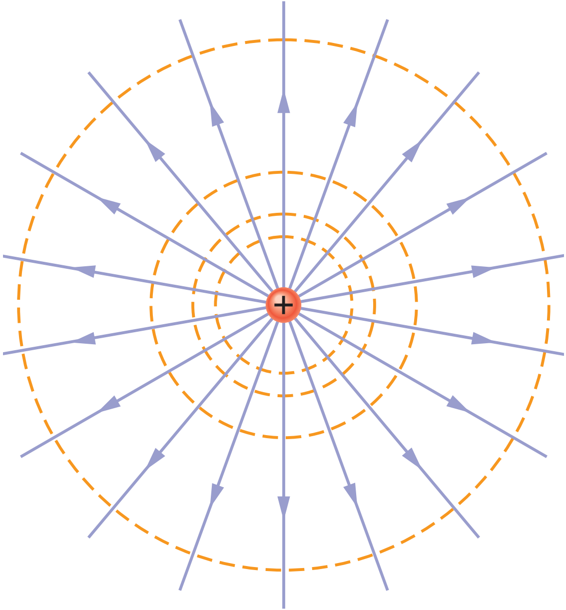
Sketching them sheds light on the potential energy a test charge would have at certain points: in particular, it is takes a particular constant value for any point on a surface.

Equipotential Surfaces: Examples



[1]Figure from Halliday, Resnick, Walker.

Equipotential Surfaces: Examples



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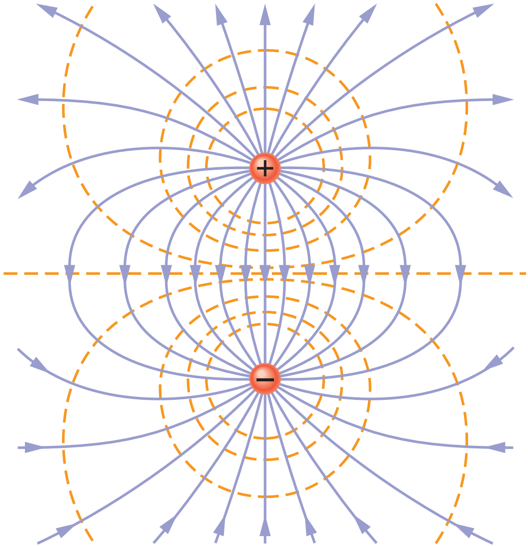
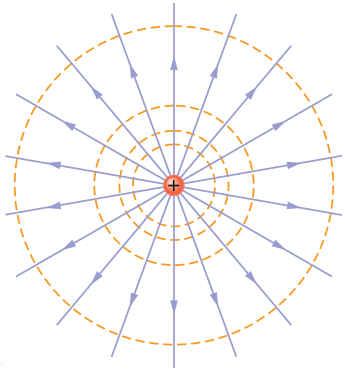


Equipotential Surfaces: Examples



Equipotential surfaces are always perpendicular to field lines.

If a charge is moved along an equipotential surface the work done by the force of the electrostatic field is zero.

Work and Potential

Recall, since the electrostatic force is a conservative force:

$$W_E = -\Delta U_E$$

W_E is the "internal work", W_{int}

So we can relate work to potential difference:

$$W_E = -q\ \Delta V$$

If we move a charge along an equipotential surface, $\Delta V = 0$ so $W_E = 0$.

Work and Potential

$$W_E = -q\ \Delta V$$

But also (assuming F is constant)

$$\begin{aligned} W_E &= Fd\cos\theta \\ -q\ \Delta V &= q\,E\,d\cos\theta \end{aligned}$$

Work and Potential

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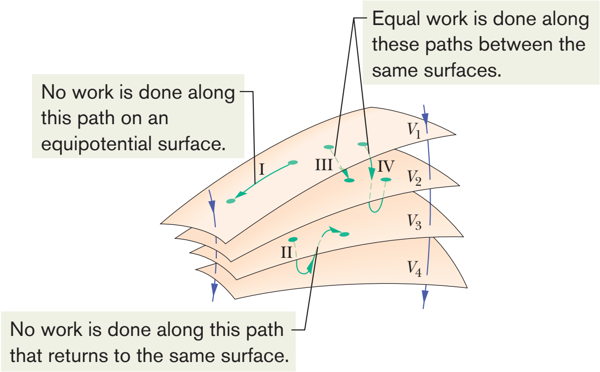
$$\begin{aligned} W_E &= Fd\cos\theta \\ -q\ \Delta V &= q\,E\,d\cos\theta \end{aligned}$$

dividing both sides by q gives:

$$\Delta V = -\mathbf{E}\cdot\mathbf{d}$$

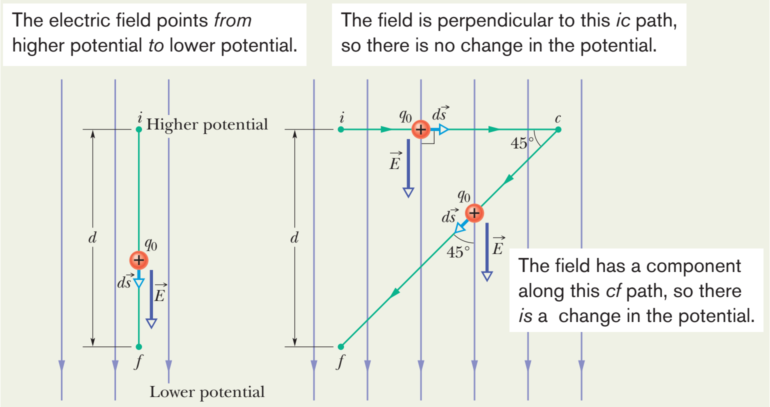
Equipotentials



No work is done by the electrostatic force moving a charge along an equipotential.

The same work is done moving a charge from one equipotential to another, regardless of the path you move it along!

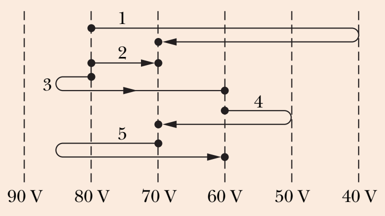
Example



[1] Halliday, Resnick, Walker, page 634.

Question

The figure 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.



1-(a) What is the direction of the electric field associated with the surfaces?

(A) rightwards

(B) leftwards

(C) upwards

(D) downwards

[1] Halliday, Resnick, Walker, page 633.

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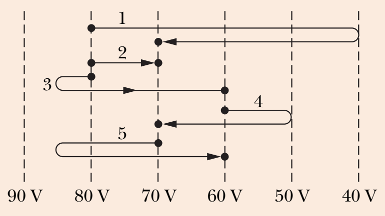

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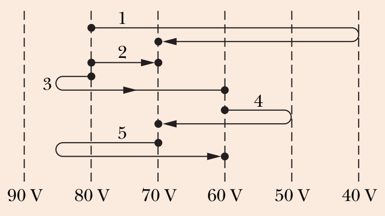

2-(c) Rank the paths according to the work *we* do, greatest first.

(A) 1, 2, 3, 4, 5

(B) 2, 4, 3, 5, 1

(C) 4, (1, 2, and 5), 3

(D) 3, (1, 2, and 5), 4

[1]Halliday, Resnick, Walker, page 633.

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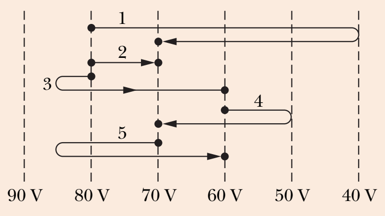

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Potential from many charges

The electric potential from many point charges could be found by adding up the potential due to each separately:

$$V_{\text{net}} = V_1 + V_2 + ... + V_n$$

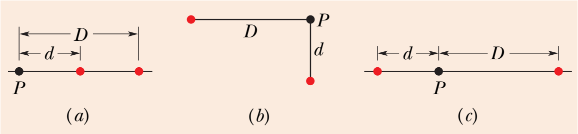
This is

$$V_{\text{net}} = \frac{k\,q_1}{r_1} + \frac{k\,q_2}{r_2} + ... + \frac{k\,q_3}{r_3}$$

Notice that this is a scalar equation, not a vector equation.

Question

The figure shows three arrangements of two protons. Rank the arrangements according to the net electric potential produced at point P by the protons, greatest first.



(A) a, b, c

(B) c, b, a

(C) b, (a and c)

(D) all the same

[1] Halliday, Resnick, Walker, page 636.

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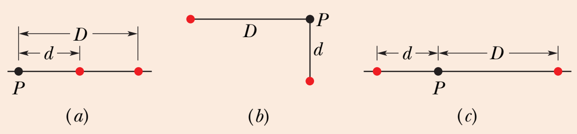

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Summary

- introduced electric potential
- related potential and work
- related potential and field

Homework Halliday, Resnick, Walker:

- Ch 24, onward from page 647. Questions: 1, 5; Problems: 1, 5, 17, 34