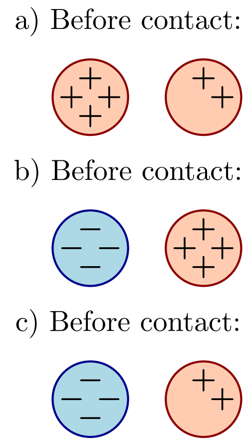
Phys 132: Exercises

Electrostatics

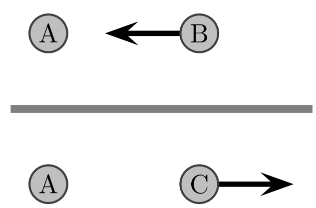
1 Charge distribution

Various identical metal spheres are separated and charged. The excess charged particles on each sphere are illustrated. Individual excess charged particles have the same magnitude of charge. The spheres are supported by insulating stands and are brought into contact and then later are separated. Determine the charge on each sphere after they have been in contact. Briefly explain your answers. *(132Sp2022)*



2 Interacting charges

Pairs of objects that may or may not be charged are placed near each other and the observed interactions are as illustrated. What interaction would occur if C were placed near to B? Explain your answer. *(132Sp2022)*



3 Interacting objects

Various objects, A, B, C and D, that may or may not be charged are placed near each other and the interactions are observed. It is observed that object A attracts object B, object A attracts object C and objects B and C do not interact. Object A repels object D. *(132Sp2022)*

a) Can one determine the types of charge of B and C with certainty? If so what are they?

b) Can one determine the types of charge of A and D with certainty? If so what are they?

c) Suppose that D is placed near to B. Explain how it will interact with B.

4 Sphere, rod and wire A metal sphere is initially uncharged. A positively charged rod is held near to but not touching the sphere. At this time a wire is briefly connected from the ground to the side of the sphere furthest from the rod and is then removed, while the rod is in place. Subsequently the rod is then removed. After all of this a small negatively charged ball is held near to the sphere. Will the sphere exert a force on the ball? If so is it repulsive or attractive? Explain your answer. *Hint: ground can supply and absorb charged particles. (132Sp2022)*

5 Charge redistribution

Two identical metal balls are initially separated and have charges q_1 and q_2. The balls are brought into contact and the charge redistributes. *(132Sp2022)*

a) Determine an expression for the charge on each ball after it has redistributed.

b) Assuming that $q_1 > q_2$, determine an expression for the number of electrons that flow from one ball to the other during the redistribution.

6 Electrons in copper

Copper consists of atoms that each have 29 electrons and mass 1.06×10^{-25} kg. Copper has a density of $8.69 \times 10^3\,\mathrm{kg/m^3}$. *(132Sp2022)*

a) Determine the number of electrons in a cube of pure copper with sides of length 2.00 cm. Assume that the copper is electrically neutral.

b) Suppose that electrons are removed from the copper so that it has a net charge of 5.00×10^{-9} C (this is a typical number for capacitors in electronic circuits). Determine the number of electrons that have been removed.

c) What fraction of the total number of electrons in the copper were removed to give it charge 5.00×10^{-9} C?

7 LHC accelerator beam dump

The Large Hadron Collider (LHC) is a high-energy physics particle accelerator at the CERN laboratory. The accelerator works by bombarding a target with high-velocity protons. Only a few of these hit the target and most of the protons need to be removed in a "beam dump." Beam dumps consist of a set of "bunches" with each bunch containing roughly the same number of protons. *(132Sp2022)*

a) Determine an expression for the total charge deposited in a beam dump in terms of the number of bunches and the number of protons in each bunch.

b) According to CERN, a typical beam dump in the LHC consists of about 2500 bunches, each with about a billion protons. Determine the charge delivered in this beam dump.

c) Each beam has a total energy of about 560 MJ and the dump lasts 86 μs. Determine the power delivered in a single beam dump. Compare this to the power delivered by a typical electrical power plant.

8 Drop of sweat

Sweat consists of water and salt. The salt is mostly sodium chloride, which consists of an equal number of sodium ions (each with one electron less that a neutral sodium atom) and chlorine ions (each with one electron more than a neutral chlorine atom). The goal of this exercise is to estimate the total charge of all the sodium ions in a drop of sweat. *(132Sp2026)*

a) Before doing any calculations, estimate the total charge (in Coulombs) of all the sodium ions in a drop of sweat.

b) Provide *a method* for estimating the total charge of all the sodium ions in a drop of sweat.

c) Use your method to estimate the total charge of all the sodium ions in a drop of sweat. Carefully describe the various quantities that you had to estimate in order to determine the total charge.

d) How accurate was your initial guess?

9 Electric forces and charge magnitude

Two charged particles, A on the left and B on the right, are held at fixed locations. The charges on the particle can be adjusted while their locations stay fixed. *(132Sp2022)*

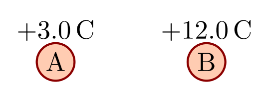
a) Suppose that the charge of B is tripled. By how many times does this increase the force that A exerts on B? Explain your answer.

b) Suppose that the charge of B is tripled. By how many times does this increase the force that B exerts on A? Explain your answer.

c) Suppose that the charge of A is tripled and the charge of B is also tripled. By how many times does this increase the force that A exerts on B? Explain your answer.

d) Suppose that the charge of A is tripled and the charge of B is also tripled. By how many times does this increase the force that B exerts on A? Explain your answer.

10 Electric forces and pairs of charges



Two charged particles, A and B, are held fixed. Let $F_{\text{A on B}}$ be the magnitude of the force exerted by A on B and $F_{\text{B on A}}$ be the magnitude of the force exerted by B on A. Which of the following is true? Explain your answer. *(132Sp2022)*

i) $F_{\text{B on A}} = \frac{1}{4} F_{\text{A on B}}$

ii) $F_{\text{B on A}} = F_{\text{A on B}}$

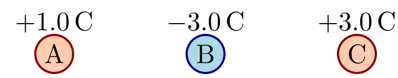
iii) $F_{\text{B on A}} = 3F_{\text{A on B}}$

iv) $F_{\text{B on A}} = 4F_{\text{A on B}}$

v) $F_{\text{B on A}} = 12F_{\text{A on B}}$

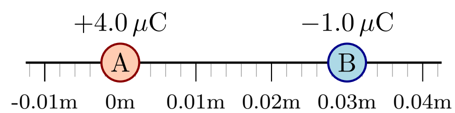
11 Electric forces and charges in a line

Three charged particles, A on the left, B in the center and C on the right, are held at fixed locations in a line. The distance between A and B is the same as between B and C. Rank the magnitudes of the net forces on each charge from smallest to largest. Explain your answer. *(132Sp2022)*



12 Linear charge arrangements and zero force

Two charged particles are held fixed as illustrated. A third charge is placed along the axis that connects the two charges (either between the charges or beyond one of them). Determine the location at which the net force on this third charge are zero. *Hint: Set up the problem using axes with the origin at one of the charges and using algebraic coordinates for the location of the third charge. (132Sp2022)*



13 Electric and gravitational forces

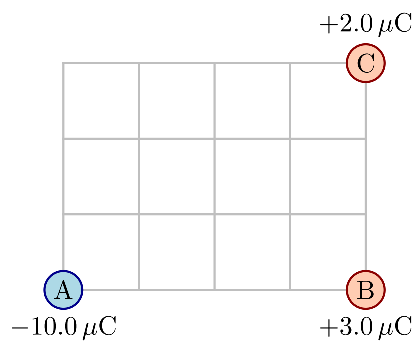
Two identical particles each have mass m and charge q and are held stationary. *(132Sp2022)*

a) Determine an expression for the ratio of the electric force exert by one on the other to the gravitational force exerted by one on the other. Does this depend on the distance between the particles?

b) Determine a numerical value for the ratio of the electric to the gravitational force for two protons. What does you result say about the importance of electrical versus gravitational forces for the constituents of ordinary matter?

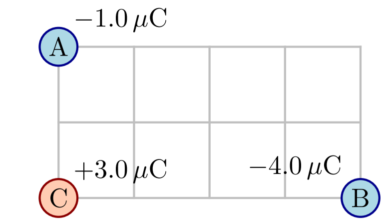
14 Two dimensional charge arrangements: force, 1

Three charged particles are held fixed as illustrated; the grid units are each 0.010 m. Determine the magnitude and direction of the net force on charge C. *(132Sp2022)*



15 Two dimensional charge arrangements: forces, 2

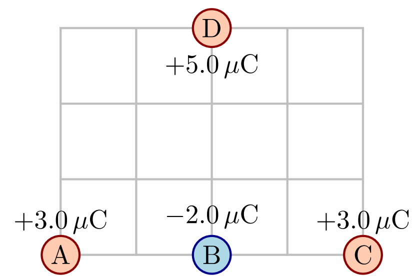
Three charged particles are held fixed as illustrated; the grid units are each 0.010 m. Determine the magnitude and direction of the net force on charge C. *(132Sp2022)*



16 Two dimensional charge arrangements: forces, 3

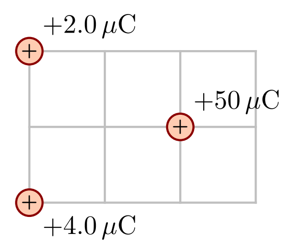
Four charged particles are held fixed as illustrated; the grid units are each 0.010 m. *(132Sp2022)*

a) Determine the net force on charge B.
b) Determine the net force on charge D.
c) Determine the net force on charge C.



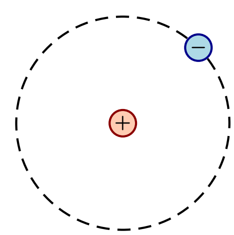
17 Two dimensional charge arrangements: forces, 4

Three charged particles are held fixed as illustrated; the grid units are each 0.20 m. Determine the net force on charge $+50\,\mu$C charge. *(132Sp2022)*



18 Orbiting charge

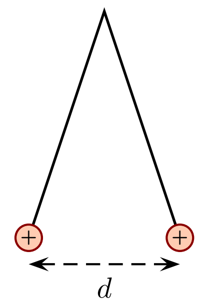
Two particles have charges that are equal in magnitude but opposite in sign. The positive charge is held fixed and the negative charge is launched in such a way that it orbits the positive charge. Let Q be the magnitude of either charge, m the mass of the orbiting charge and r the radius of orbit. *(132Sp2022)*



a) Starting with Newton's second law and using kinematics for uniform circular motion, determine an expression the speed of orbit v in terms of Q, m, r and constants.
b) Determine an expression for the time taken to complete one orbit, T in terms of Q, m, r and constants.
c) In a hydrogen atom the electron's orbital radius is approximately 10^{-10} m. Determine the time taken to complete one orbit.

19 Suspended charges

Two identical small metal spheres are each suspended from a string with length L. Each sphere is given the same charge q and they repel and reach an equilibrium state where they are a distance d apart. The mass of each sphere is m. *(132Sp2022)*



a) Determine an expression for q in terms of m, d, L and constants.

b) In a real case the mass of each ball is 8.0 g, each string is 25 cm long and the separation is 5.0 cm. Determine the charge on each ball.

20 Levitating polystyrene ball

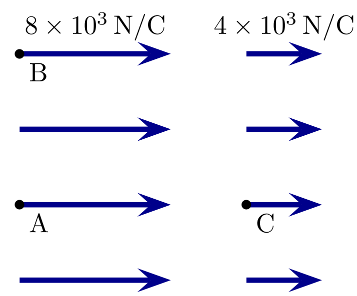
A small 2.5 g polystyrene ball is placed in a device which produces a 3000 N/C uniform electric field pointing vertically upwards; this field could easily be produced with standard laboratory equipment. *(132Sp2022)*

a) What charge would the ball need in order to levitate at rest?

b) Suppose that the ball were levitating at rest and it suddenly lost half of its charge. How long would it take for the ball to drop a distance of 1.0 cm?

21 Electric field and forces at various locations

Hidden source charges produce the illustrated electric field. *(132Sp2022)*



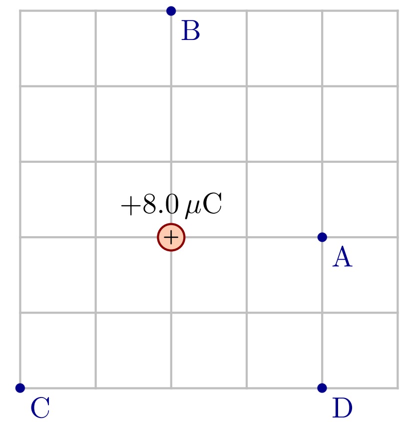
a) Determine the force exerted on a proton that is placed at A. Determine the acceleration of a proton at this point.

b) Determine the force exerted on an electron that is placed at B. Determine the acceleration of an electron at this point.

c) Determine the force exerted on an electron that is placed at C. Determine the acceleration of an electron at this point.

22 Electric field at various locations

A charged particle is held fixed as illustrated; the grid units are each 0.010 m. Determine the electric field vector components at each point A,B,C and D. Draw the vectors on the diagram (or on a copy of the diagram). *(132S22)*



23 Air breakdown field

Air breaks down (produces sparks and lightning) when the electric field reaches about 3.0×10^6 N/C. A metal sphere with radius 0.20 m carries a charge uniformly distributed on its surface and in this case, outside the sphere, the electric field is exactly the same as that produced if all the charge were concentrated at the center. Determine the charge that the sphere must carry so that the air at its surface breaks down. *(132S22)*

24 Electric fields and forces

Two charged particles (sources) are held at fixed locations. A probe charge is placed at location A. Which of the following is true? Explain your answer. *(132S22)*

i) The electric field at A is zero because the total charge is zero.

ii) The electric field at A points in one direction for a positive probe and the opposite for a negative probe; the force on the probe points in the same direction regardless of the probe.

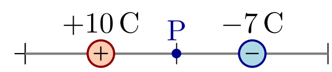
iii) The electric field at A points in one direction for a positive probe and the opposite for a negative probe; the force on the probe points one direction for a positive probe and the opposite for a negative probe.

iv) The electric field at A points in the same direction regardless of the probe charge; the force on the probe points in the same direction regardless of the probe charge.

v) The electric field at A points in the same direction regardless of the probe charge; the force on the probe points in different directions depending the probe charge.

25 Electric fields and forces between two charged particles.

Two charged particles are held at fixed locations. Various probe charges are placed at the midpoint. *(132Sp22)*



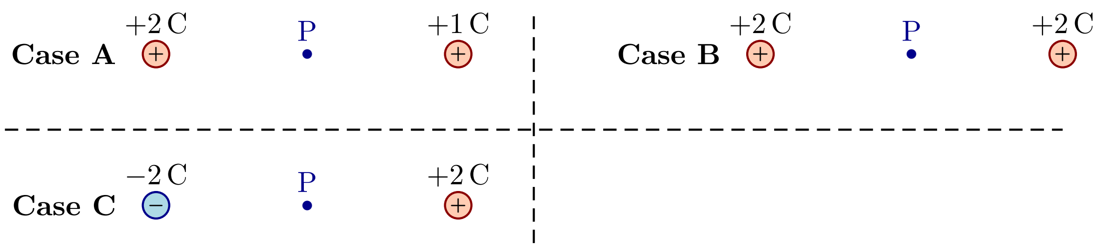
a) Does the direction and magnitude of the electric field produced by the two illustrated particles change when a positive probe at P is replaced by a negative probe at P?

b) Do the direction and magnitude of the force exerted on a probe placed at P change when a positive probe is replaced by a negative probe?

Explain your answers.

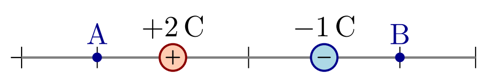
26 Electric field ranking

Three isolated pairs of charges are separated by the same distance in the three situations illustrated below. Rank the magnitudes of the electric fields at the midpoints (labeled P) from smallest to largest. Explain your answers. *(132Sp22)*



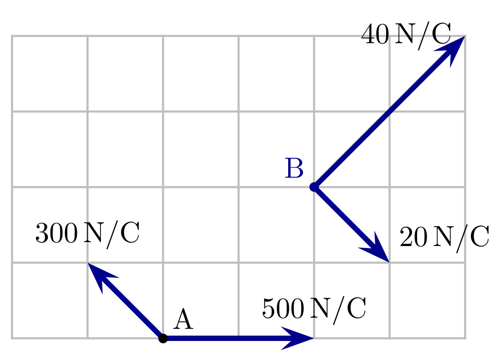
27 Electric fields at different locations

Two charged particles are held at fixed locations. Is the magnitude of the electric field produced by these charges at point A larger than, smaller than or the same as at point B? Explain your answer. *(132Sp22)*



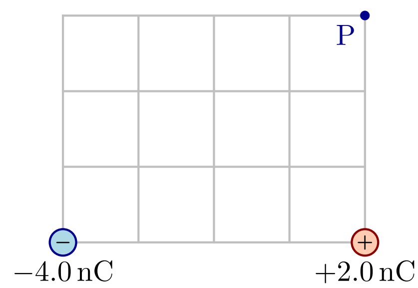
28 Net electric field

Two hidden arrangements of charged particles each produce an electric field, i.e. one electric field vector at each point. These are illustrated at two points. The net electric field at any point is the sum of the two field vectors at each point. Use vector components to determine the net electric field at point A and the net electric field at point B. *(132S22)*



29 Electric field produced by two point charges, 1

Two charged particles are held fixed as illustrated; the grid units are each 0.010 m. The aim of this exercise will be to determine the field at point P. *(132S22)*



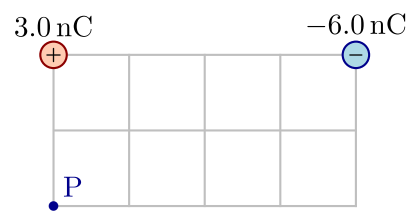
a) Indicate the directions of the electric fields produced by each source charge at point P.

b) Determine the magnitude of the electric field produced by each source charge at point P.

c) Using vector components add the two electric fields. Express the total electric field in terms of standard unit vectors.

30 Electric field produced by two point charges, 2

Two charged particles are held fixed as illustrated; the grid units are each 0.010 m. The aim of this exercise will be to determine the field at point P. *(132S22)*



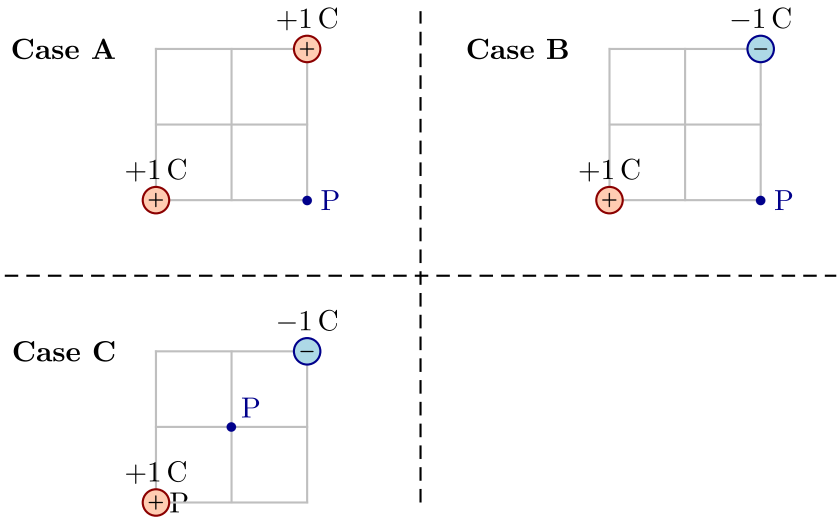
a) Indicate the directions of the electric fields produced by each source charge at point P.

b) Determine the magnitude of the electric field produced by each source charge at point P.

c) Using vector components add the two electric fields. Sketch the net electric field vector and determine its magnitude.

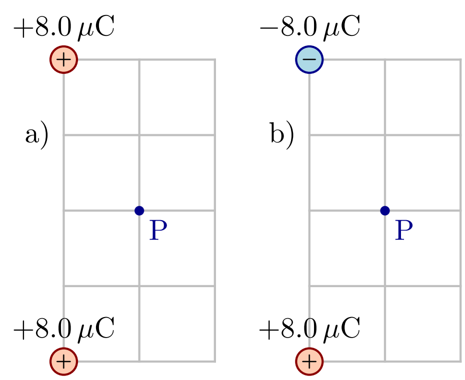
31 Ranking electric fields in two dimensions

Three arrangements of two charged particles are as illustrated. Rank the electric fields in order of increasing magnitude, indicating equal cases where applicable. Explain your answer. *(132S22)*



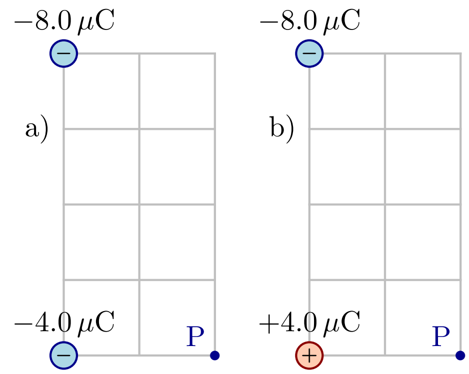
32 Electric field produced by two charges in two dimensions, 1

In each of the following, fixed charges are held fixed as illustrated. The grid units are each 0.020 m. Determine the electric field at point P in each case. *(132S22)*



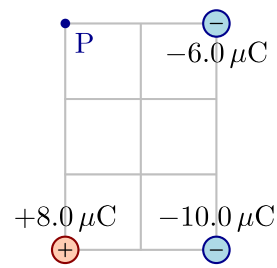
33 Electric field produced by two charges in two dimensions, 2

In each of the following, fixed charges are held fixed as illustrated. The grid units are each 0.020 m. Determine the electric field at point P in each case. *(132S22)*



34 Electric field produced by multiple charges in two dimensions

Three charged particles are held fixed as illustrated; the grid units are each 0.020 m. *(132S22)*



a) Determine the electric field at point P.

b) A particle with charge $+3.0\,\mu$C is placed at P. Determine the force exerted on this particle by the other charged particles.

c) A particle with charge $-3.0\,\mu$C is placed at P. Determine the force exerted on this particle by the other charged particles.

35 Carbon monoxide dipole

Carbon monoxide is a molecule consisting of a single carbon and a single oxygen atom. The separation between these is roughly 1.0×10^{-10} m. The dipole moment of carbon monoxide is 4.07×10^{-31} C· m. *(132S22)*

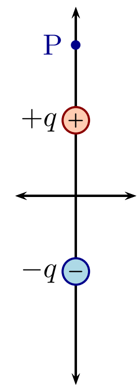
a) If the carbon monoxide molecule were to be modeled as a dipole consisting of a positive and a negative charge separated by 2.0×10^{-10} m, determine the magnitudes of these charges.

b) Determine the electric field along the dipole axis at a distance 20 nm from the center of the carbon monoxide molecule.

c) An electron is held at rest along the dipole axis at a distance 3.0×10^{-7} m from the center of the carbon monoxide molecule and is then released. Determine the acceleration of the electron at the moment it starts to move.

36 Electric field produced by a dipole

A point dipole consists of two opposite charges oriented along the y axis as illustrated. The distance between the point charges is d. With the origin midway between the two charges, the vertical component of the field at point P is



$$E_y = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{(y-d/2)^2} - \frac{1}{(y+d/2)^2}\right]$$

where y is the vertical coordinate of P. The aim of this exercise is to show how a strategy of using approximations lets one arrive at the formula for the dipole field. *(132S22)*

a) Show that $(y \pm d/2)^2 = y^2(1 \pm d/2y)^2$.

b) Show that

$$E_y = \frac{1}{4\pi\epsilon_0}\frac{q}{y^2}\left[\frac{1}{(1-d/2y)^2} - \frac{1}{(1+d/2y)^2}\right].$$

Calculus gives a series (called a Taylor series) for any function. In this case, the relevant series is

$$\frac{1}{(1+x)^2} = 1 - 2x + 3x^3 - 4x^3 + \cdots .$$

If x is much less than 1 (written $x \ll 1$) then x^2, x^3, x^4 are all much smaller than x. Thus, to a good approximation,

$$\frac{1}{(1+x)^2} \approx 1 - 2x.$$

Similarly

$$\frac{1}{(1-x)^2} \approx 1 + 2x.$$

c) Assuming that $y \ll d$, then with $x = d/2y$, use the series approximation to show that

$$E_y \approx \frac{1}{4\pi\epsilon_0}\frac{q}{y^2}\frac{2d}{y} = \frac{1}{4\pi\epsilon_0}\frac{2p}{y^3}$$

where $p = qd$.

37 Field produced by a uniformly charged rod

A uniformly charged rod is oriented as illustrated. The length of the rod is L and the total charge (positive) is Q. The aim of this is to determine the electric field at P. *(132S22 Class)*

a) As an example, suppose that the length of the rod is 2.0 m and the total charge is 60 C. Determine the charge density and use it to determine the charge in any segment of the rod with length 0.010 m. Repeat this for a segment with length 0.0050 m.

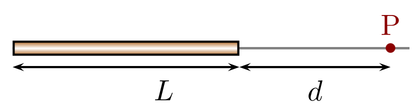
b) Consider a segment from $x \to x + \mathrm{d}x$ where x is some point in the rod. Write expressions for the length of the segment and the charge it contains (in terms of dx and λ).

c) Indicate the field produced by this segment and determine an expression for its components (in terms of $x_p, x, \mathrm{d}x$ and λ).

d) Write an expression (eventually in terms of calculus) for the components of the net electric field produced by all segments.

38 Field produced by a non-uniformly charged rod

A rod with length L carries total charge $Q > 0$. The charge is distributed along the rod non-uniformly but it is not all at the either end of the rod. Consider the electric field at the point P, a distance d from the right end of the rod. Which of the following is true about the magnitude of the field? Explain your answer.



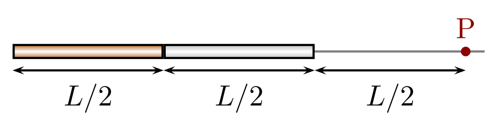
i) $E < \dfrac{1}{4\pi\epsilon_0} \dfrac{Q}{(L+d)^2}$

ii) $\dfrac{1}{4\pi\epsilon_0} \dfrac{Q}{(L+d)^2} < E < \dfrac{1}{4\pi\epsilon_0} \dfrac{Q}{d^2}$

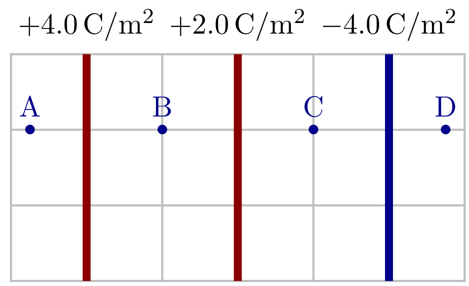
iii) $\dfrac{1}{4\pi\epsilon_0} \dfrac{Q}{d^2} < E$

39 Field produced by a dipolar charged rod

A rod with length L has charge distributed in two segments. The left half has total charge $-Q$ that is uniformly distributed (in the left half). The right half has total charge Q. Determine an expression, in terms of L, Q, d and constants, for the electric field at a P, exactly distance $L/2$ from the right end of the rod.

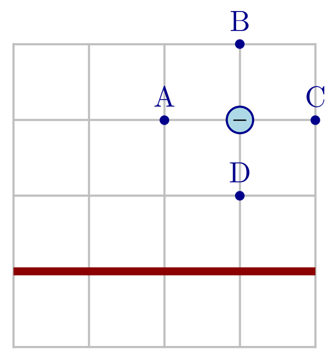


40 Electric fields produced by planes



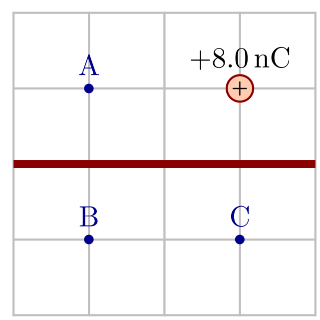
Several parallel uniformly charged infinite planes, with indicated surface charge densities, are as illustrated. Rank the magnitudes of the electric fields at the indicated points, A, B, C and D. Explain your answer. *(132S22)*

41 Electric field produced by point charge and plane



A point charge is held in the vicinity of a uniformly charged infinite plane as illustrated. The plane carries positive charge. Rank the magnitudes of the electric fields at the indicated points, A, B, C and D. Explain your answer. *(132S22)*

42 Electric field produced by point charge and plane



A point charge is held in the vicinity of a uniformly charged infinite plane as illustrated. The surface charge density on the sheet is $+1.5 \times 10^{-7}\,\mathrm{C/m^2}$. The grid units are each $0.040\,\mathrm{m}$. *(132S22)*

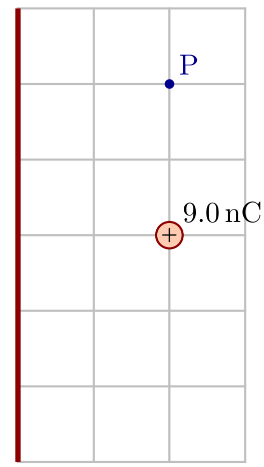
a) Determine the net electric field at point A.

b) Determine the net electric field at point B.

c) Determine the net electric field at point C.

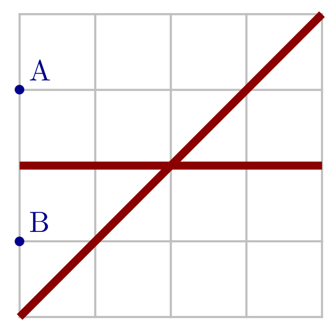
43 Field produced by sheet and point charge

A sheet with area $5.0\,\mathrm{m}^2$ carries total charge $250\,\mathrm{nC}$. A point particle with charge $9.0\,\mathrm{nC}$ is $0.0050\,\mathrm{m}$ to the right of the sheet. Determine the net electric field at point P, a distance $0.10\,\mathrm{m}$ from the point charge. *(132S22 Class)*



44 Electric fields produced by planes

Two uniformly charged infinite planes intersect at an angle of 45°, as illustrated. Each carries charge density $5.0 \times 10^{-6}\,\mathrm{C/m}^2$. The grid units are $0.010\,\mathrm{m}$. *(132S22)*



a) Determine the net electric field at point A.

b) Determine the net electric field at point B.