# Electricity and Magnetism
# Electric Field

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# Last time

- Coulomb's Law
- force from many charges

# Warm Up Question

**10** In Fig. 21-20, a central particle of charge $-2q$ is surrounded by a square array of charged particles, separated by either distance $d$ or $d/2$ along the perimeter of the square. What are the magnitude and direction of the net electrostatic force on the central particle due to the other particles? (*Hint:* Consideration of symmetry can greatly reduce the amount of work required here.)

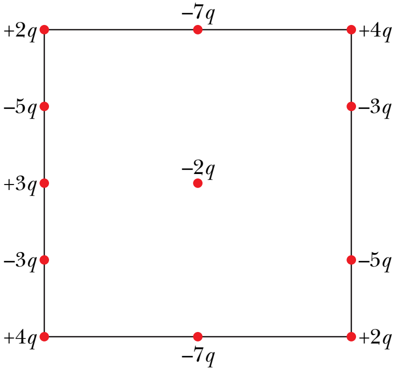


**Fig. 21-20** Question 10.

# Overview

- forces at a fundamental level
- electric field
- field from many charges
- electric field lines
- net electric field

# Forces at a Fundamental Level

Often people think about two kinds of forces: contact forces and field forces (*ie.* forces that act at a distance).

In mechanics problems, all forces except gravity are from direct contact.

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And actually, at a fundamental level, *all* forces that we know of are field forces.

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| Force | $\sim$ Rel. strength | Range (m) | Attract/Repel | Carrier |
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| Gravitational | $10^{-38}$ | $\infty$ | attractive | graviton |
| Electromagnetic | $10^{-2}$ | $\infty$ | attr. & rep. | photon |
| Weak Nuclear | $10^{-13}$ | $< 10^{-18}$ | attr. & rep. | $W^+$, $W^-$, $Z^0$ |
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Gravity is actually quite a weak force, but it is the only one that (typically) matters on large scales - charges cancel out!

# Fields

**field (physics)**

A field is any kind of physical quantity that has values specified at every point in space and time.

# Vector Fields

In EM we have vector fields. The electrostatic force is mediated by a vector field.

**vector field (physics)**

any kind of physical quantity that has values specified *as vectors* at every point in space and time.

**vector field (math, 3 dimensions)**

A vector field is a vector-valued function $\mathbf{F}$ that takes a point $(x, y, z)$ and maps it to a vector $\mathbf{F}(x, y, z)$.

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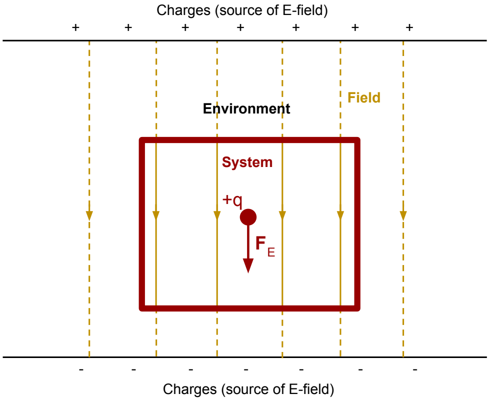
# Fields

Imagine a charge $q_0$. We want to know the force it would feel if we put it at a specific location.

The electric field $\mathbf{E}$ at that point will tell us that!

$$\mathbf{F} = q_0 \mathbf{E}$$



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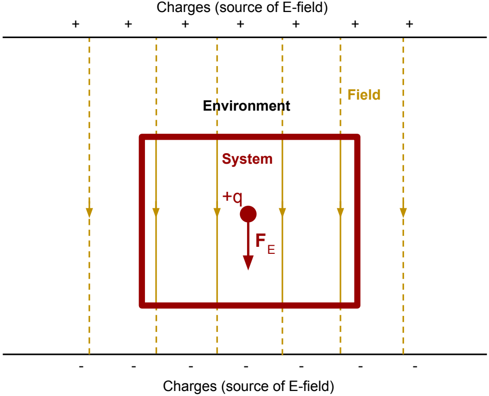
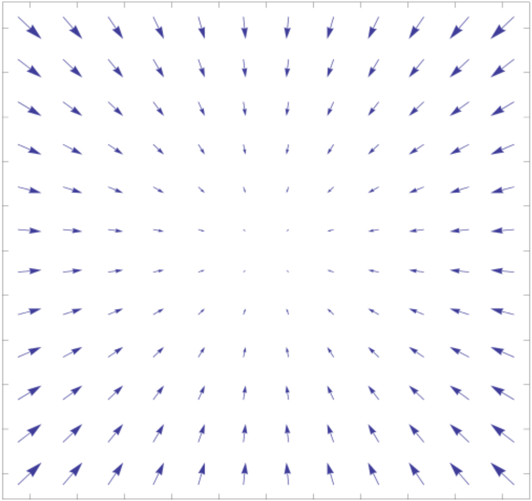



The source of the field could be another charge or charges, but we do not need a description of the sources of the field to describe what their effect is on our particle. All we need to know is the field!

(This is also true for gravity. We do not need the mass of the Earth to know something's weight: $\mathbf{F}_G = m_0\mathbf{g}$.)

# Vector Fields

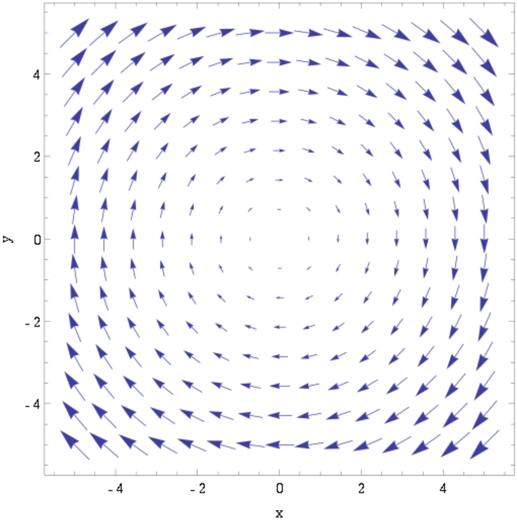
2 - dimensional examples



Irrotational (curl-free) field.

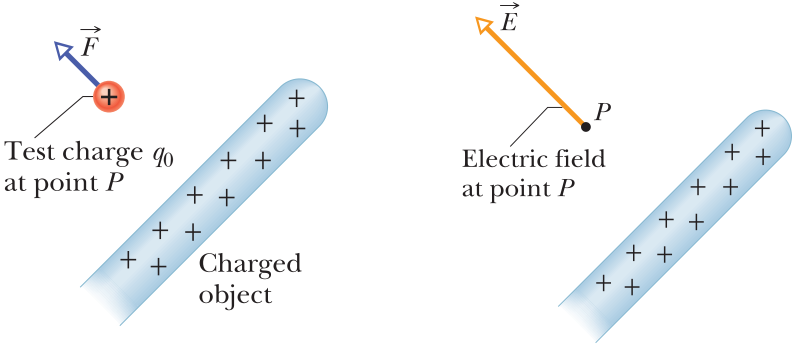
# Vector Fields

2 - dimensional examples




Solenoidal (divergence-free) field.

# Force from an Electic Field




$$\mathbf{F} = q_0 \mathbf{E}$$

but also:

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}$$

[1] Figure from Halliday, Resnick, Walker.

# E-Field from a Point Charge

We want an expression for the electric field from a point charge, $q$.

Using **Coulomb's Law** the force on the test particle is $\mathbf{F}_{\to 0} = \frac{k\,q q_0}{r^2}\hat{\mathbf{r}}$.

$$\mathbf{E} = \frac{\mathbf{F}}{q_0} = \left(\frac{1}{\cancel{q_0}}\right)\frac{k\,q\,\cancel{q_0}}{r^2}\hat{\mathbf{r}}$$

The field at a displacement $\mathbf{r}$ from a charge $q$ is:

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# Field from a Point Charge

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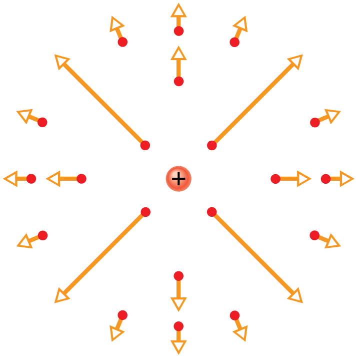
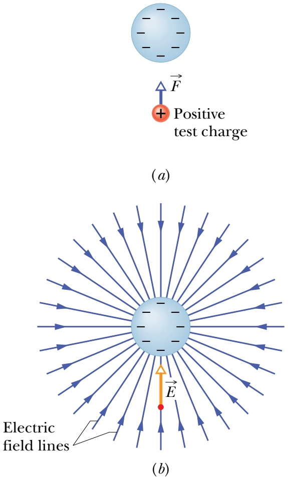
This is a vector field:



# Field Lines

Fields are drawn with lines showing the **direction** of force that a test particle will feel at that point. The **density** of the lines at that point in the diagram indicates the approximate magnitude of the force at that point.



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$$\mathbf{F}_{\text{net},0} = \mathbf{F}_{1\to 0} + \mathbf{F}_{2\to 0} + ... + \mathbf{F}_{n\to 0}$$

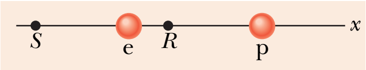
$\mathbf{E}_{\text{net}} = \frac{\mathbf{F}_{\text{net}}}{q_0}$

Total electric field:

$$\mathbf{E}_{\text{net}} = \mathbf{E}_1 + \mathbf{E}_2 + ... + \mathbf{E}_n$$

# Question about field from point charges

Consider a proton $p$ and an electron $e$ on an $x$ axis.




What is the direction of the electric field **due to the electron only** at point $S$ and point $R$?

**(A)** leftward at $S$, leftward at $R$

**(B)** leftward at $S$, rightward at $R$

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**(D)** rightward at $S$, rightward at $R$

[1] Figure from Halliday, Resnick, Walker, page 583.

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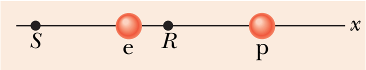


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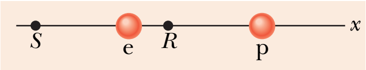


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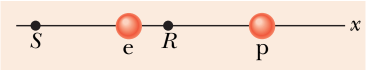


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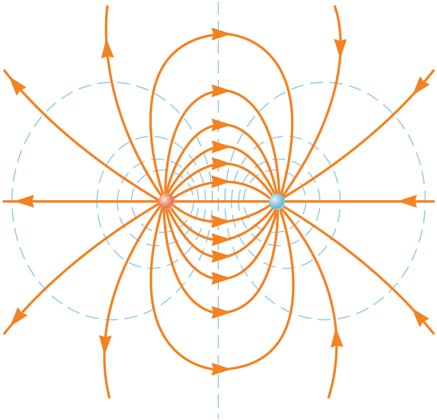
# Field Lines

The electrostatic field caused by an electric dipole system looks something like:



Notice that the lines point **outward** from a positive charge and **inward** toward a negative charge.

[1]Figure from Serway & Jewett

# Summary

- vector fields
- electric field
- field of a point charge
- net field

## Homework

- Collected homework 1, posted online, due on Monday, Jan 22.

Serway & Jewett:

- Read Ch 23
- Ch 23, onward from page 716. Section Qs: 23, 33, 47, 49