PHY294H

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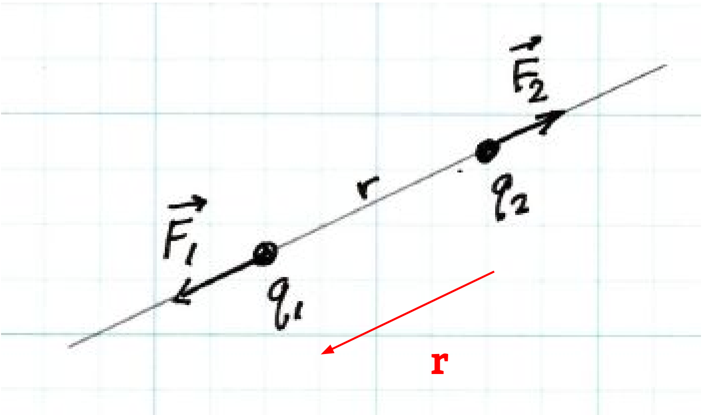
- email:huston@msu.edu
- office: BPS3230
- textbook: Knight, Physics for Scientists and Engineers: A Strategic Approach,
  - Vol. 4 (Chs 25-36), 3/E + MasteringPhysics
    0321844297
  - MasteringPhysics (complete ebook) access card stand alone
    0321753054
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - first MP assignment due Wed Jan. 20; first hand-written problem as well
- Quizzes by iclicker (sometimes hand-written)
- Lectures: MTWTh 11:30-12:20
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

THE COULOMB FORCE

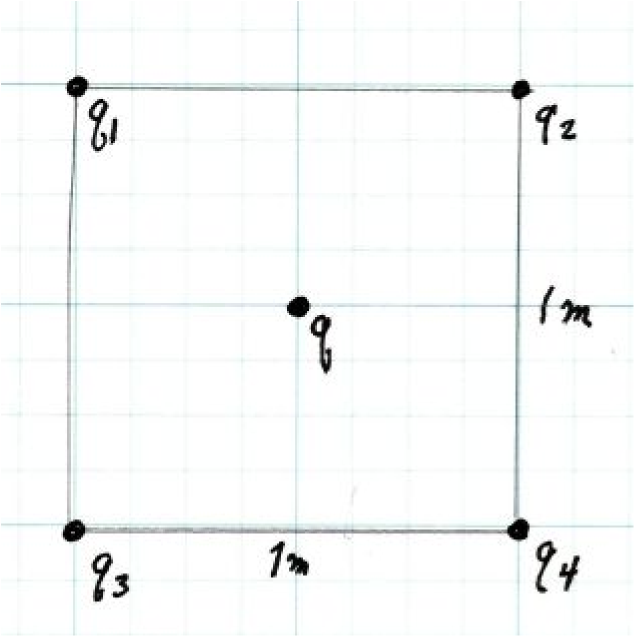
$$\mathbf{F_1} = \frac{q_1\, q_2}{4\,\pi\,\varepsilon_0\, r^2}\;\hat{\mathbf{r}}$$

$$\mathbf{F_2} = \frac{q_1\, q_2}{4\,\pi\,\varepsilon_0\, r^2}\;(-\,\hat{\mathbf{r}})$$



What if there are several charges?

- See the figure.
- The total (or net) force is the sum of the individual forces.
  - "Principle of Superposition"
  - The total (or net) force on q is
  - $\mathbf{F_T = F_1 + F_2 + F_3 + F_4}$
- Important: they are added as vectors.



What if there are several charges?

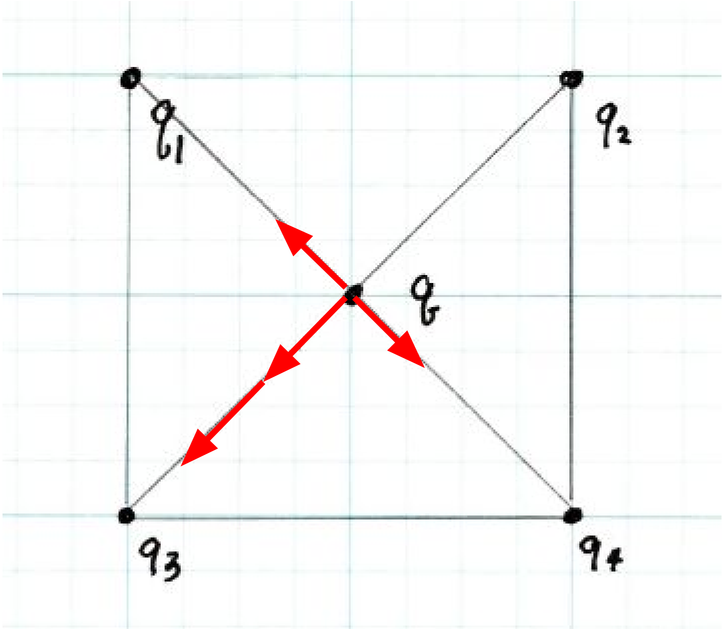
q = 1 μC

q1 = 2 μC

q2 = 3 μC

q3 = -3 μC

q4 = 2 μC



Force on q due to a continuous charge distribution

- Consider the interaction of an infinitesimal volume element with the point charge q

$$\Delta \vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q\,\Delta q}{r'^2}\hat{r}'$$

- Assume charge density ρ(r'); the charge in the volume element is

$$\Delta q = \rho(\vec{r}')\,\Delta V'$$

- So the force on q due to the volume element is

$$\Delta \vec{F} = \frac{q}{4\pi\epsilon_0} \frac{\rho(\vec{r}')}{r'^2} \Delta V'$$

- The net force is

$$\vec{F} = \frac{q}{4\pi\epsilon_0} \int \frac{\rho(\vec{r}')}{r'^2}\hat{r}'\, dV'$$

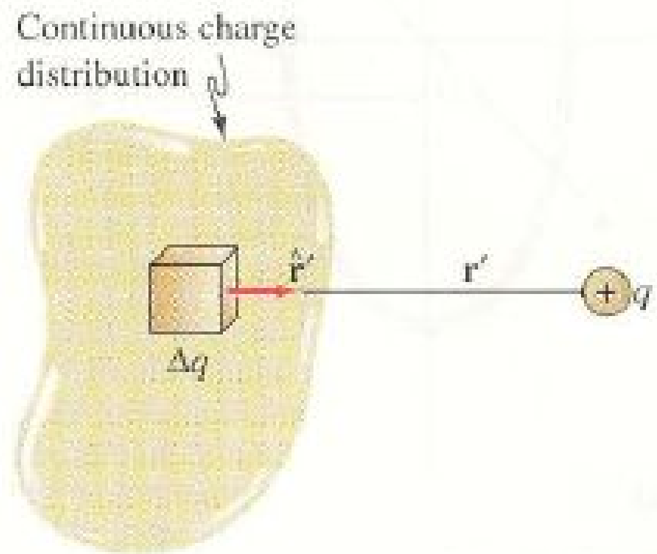
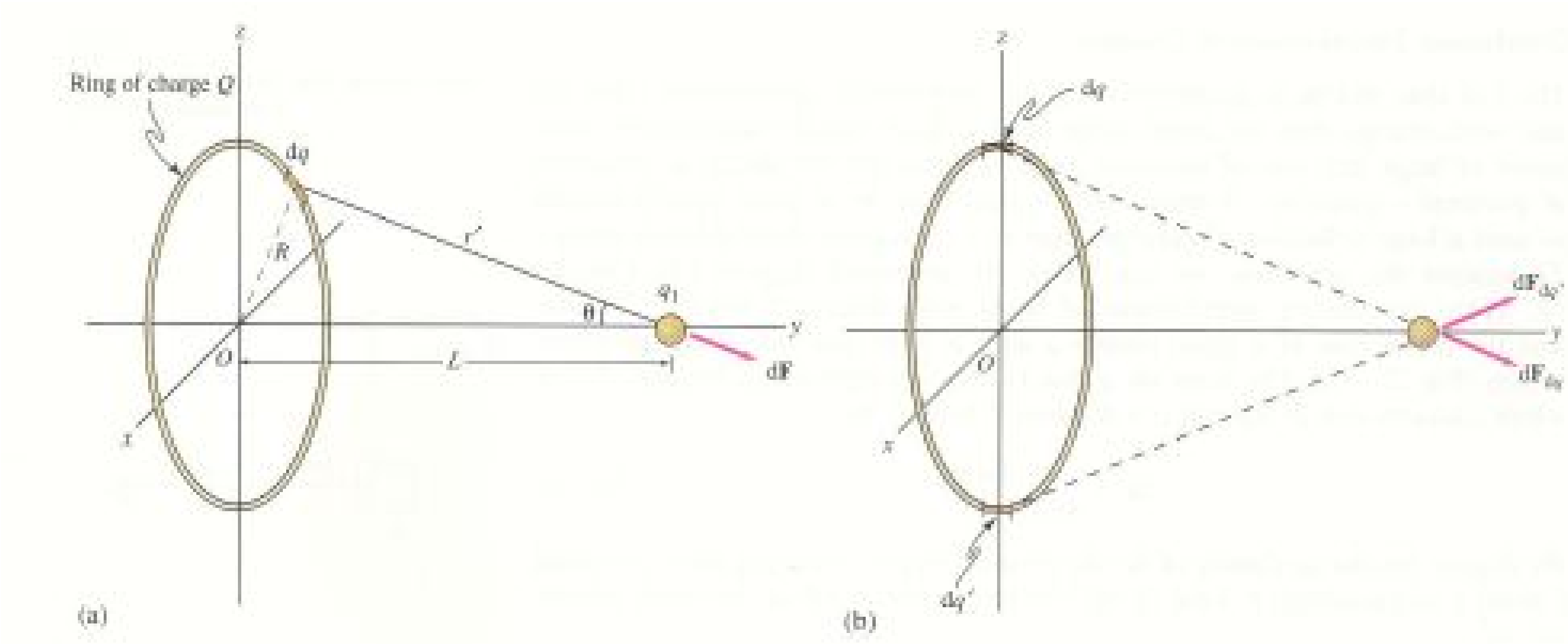
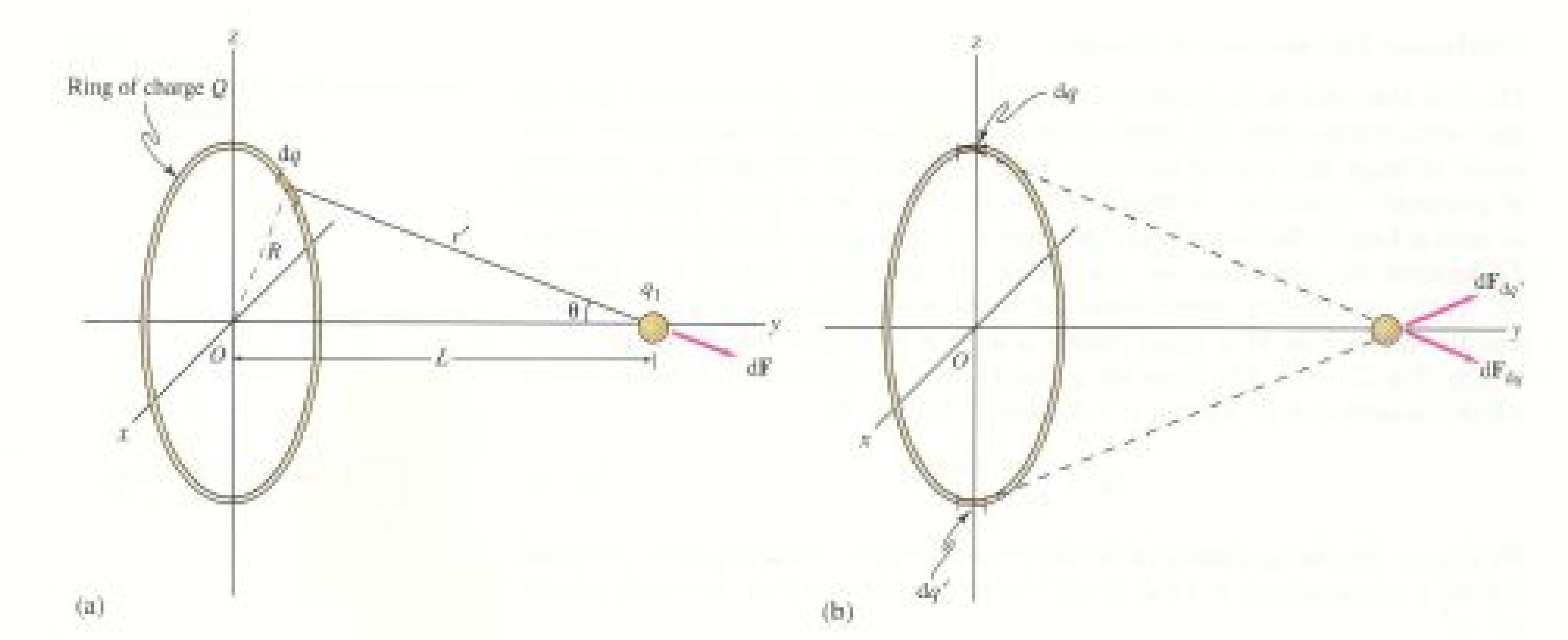


FIGURE 22–13 To find the total force on a point charge q due to a continuous charge distribution, integrate over the tiny charge elements Δq. Notice that the vector $\hat{r}'$ will change as we move through the distribution.

Example: force on a point charge due to a charged ring



Example: force on a point charge due to a charged ring

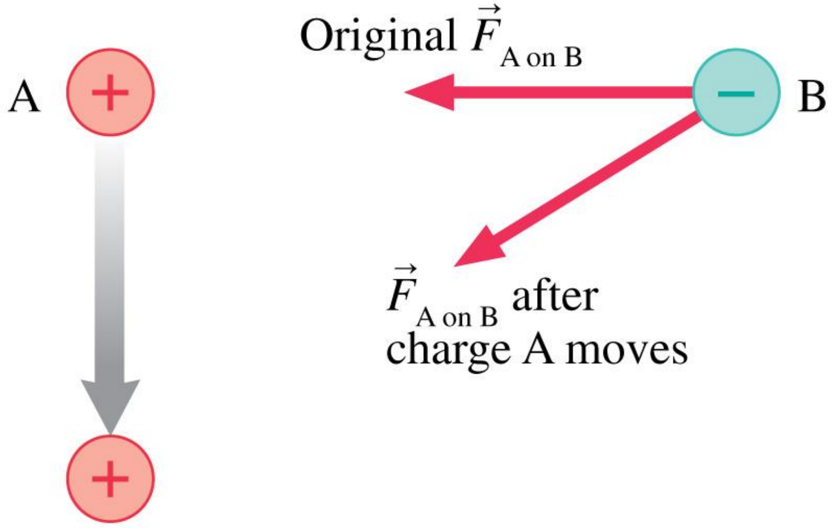


- Consider charge element dq
- Every element dq is same distance (r') from point charge q_1
- Magnitude of force |dF| from each element is the same
- Direction is not; from symmetry note that (x,z) components will cancel upon integration
- y components will add

$$F_y = \frac{1}{4\pi\varepsilon_0}\frac{Q\,q_0\,L}{(L^2+R^2)^{3/2}}$$

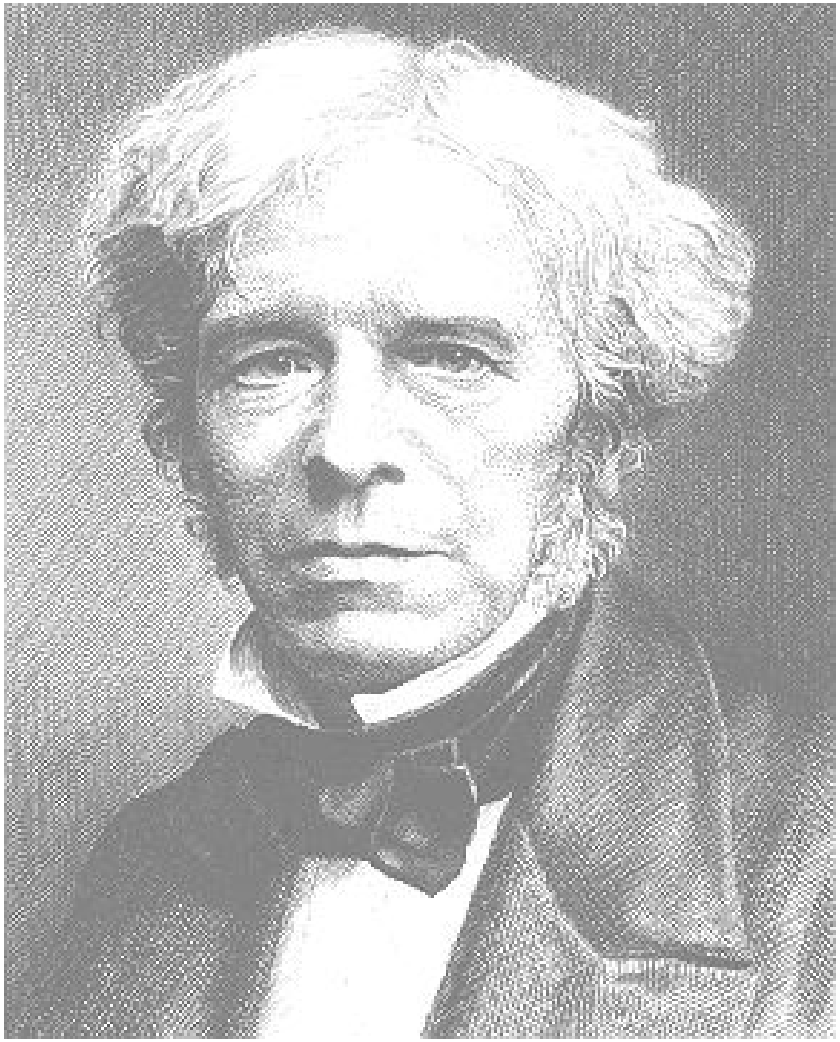
Action at a distance

- How is force from A to B transmitted through space?
- Best Newton could come up with was *action at a distance*
- Unsatisfying since no mechanism to explain how force is transmitted
- And what if A is moving with respect to B
- How quickly does B know about A's new position?
  - Newton would say instantaneously



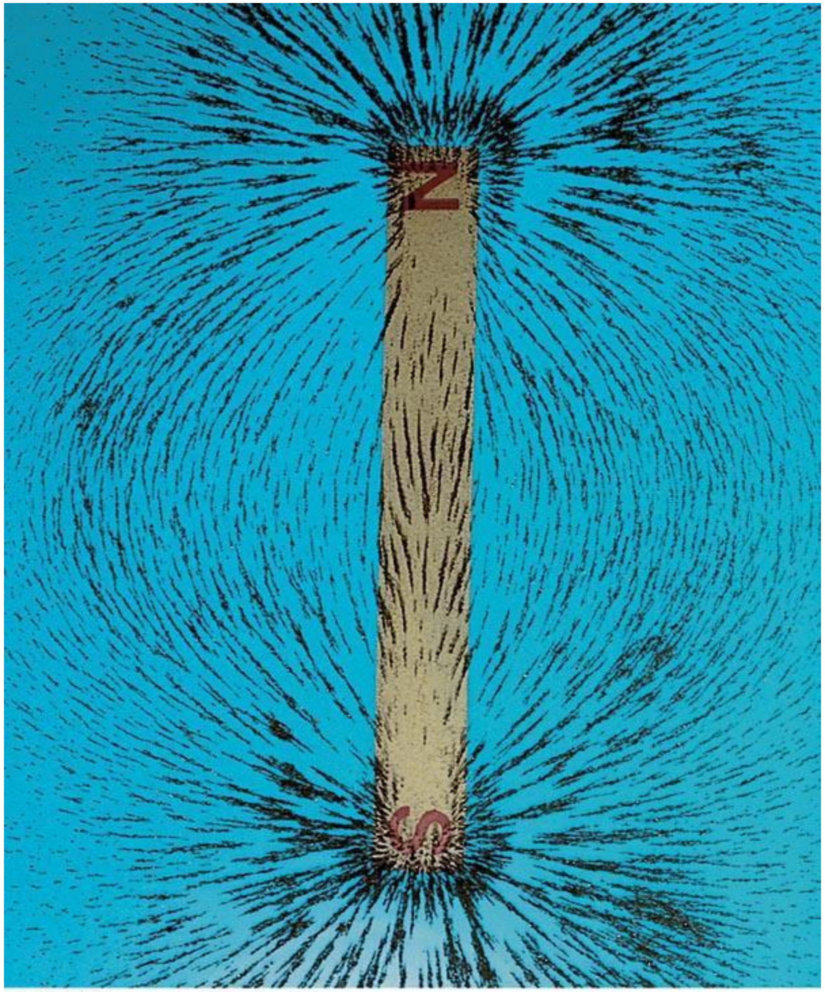
Enter Michael Faraday

- 1791 – 1867
- Chemist and Physicist
- Self-taught
- Responsible for
  - modern electric motor, generator, and transformer
- We'll see his name many times during the course
- And I have two short videos about him

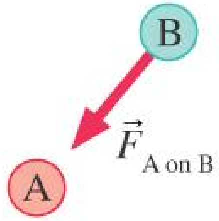


Fields

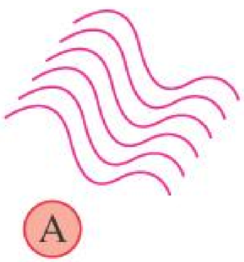
- Faraday was struck by the way iron filings lined up around a bar magnet .
- Perhaps the magnet is altering space around itself, and this alteration is responsible for the long range force .
- Faraday's idea (he called it "lines of force") came to be called a ***field .***
- It's very intuitive (like most of Faraday's thoughts) but the idea of a field was placed on a firm mathematical footing later by James Clerk Maxwell.



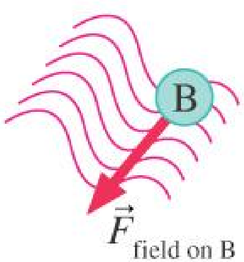
Compare "action at a distance" and "field"



In the Newtonian view, A exerts a force directly on B.



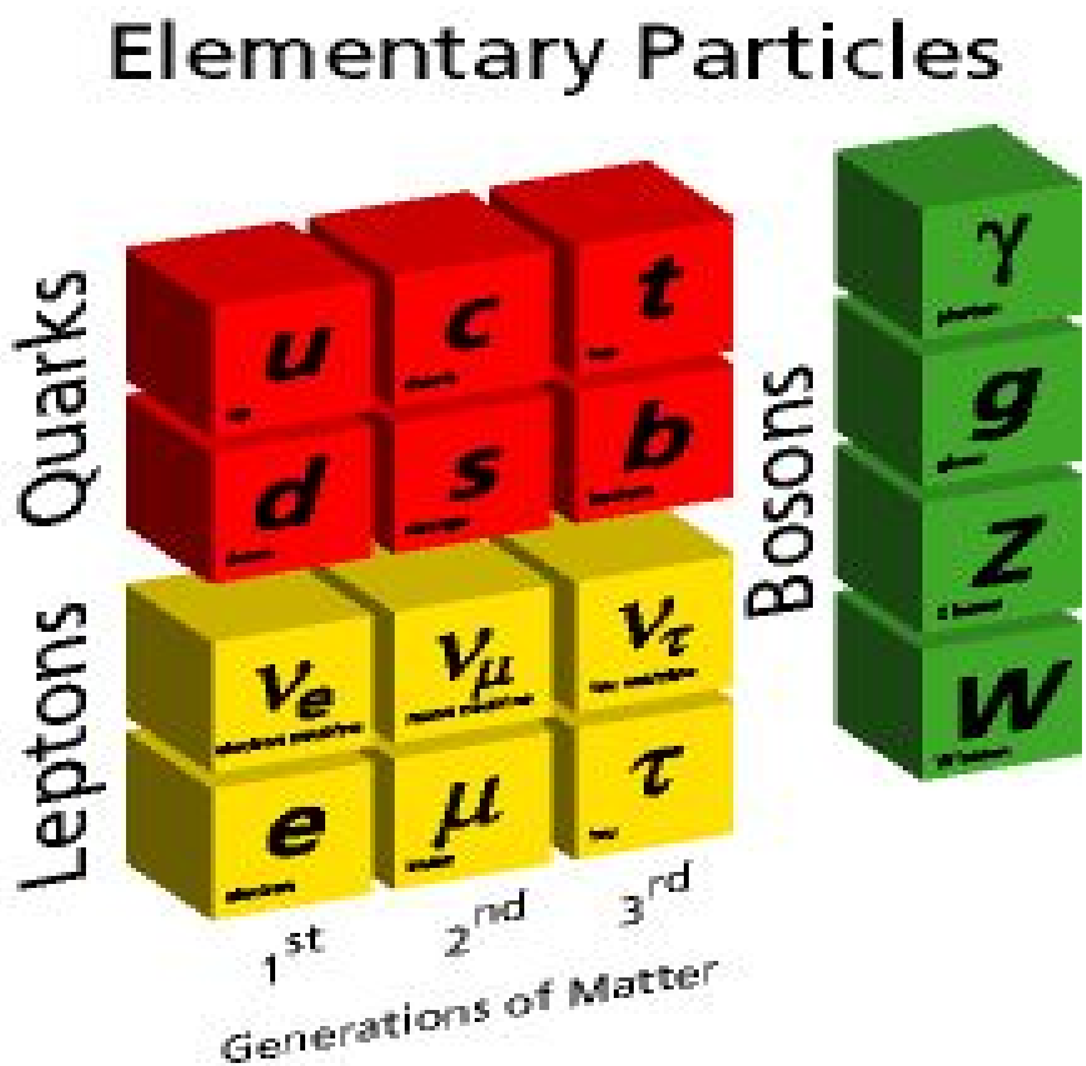
In Faraday's view, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)



Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

- So we're going to replace the idea of action at a distance by the concept of a field .
- Particles don't interact directly with each other .
- They create fields which then interact with the other particles.
  - We will need this when we start talking about dynamic situations.
- We'll be dealing with both electric and magnetic fields in this course . In fact they are related; there is a unified field theory.

In modern language

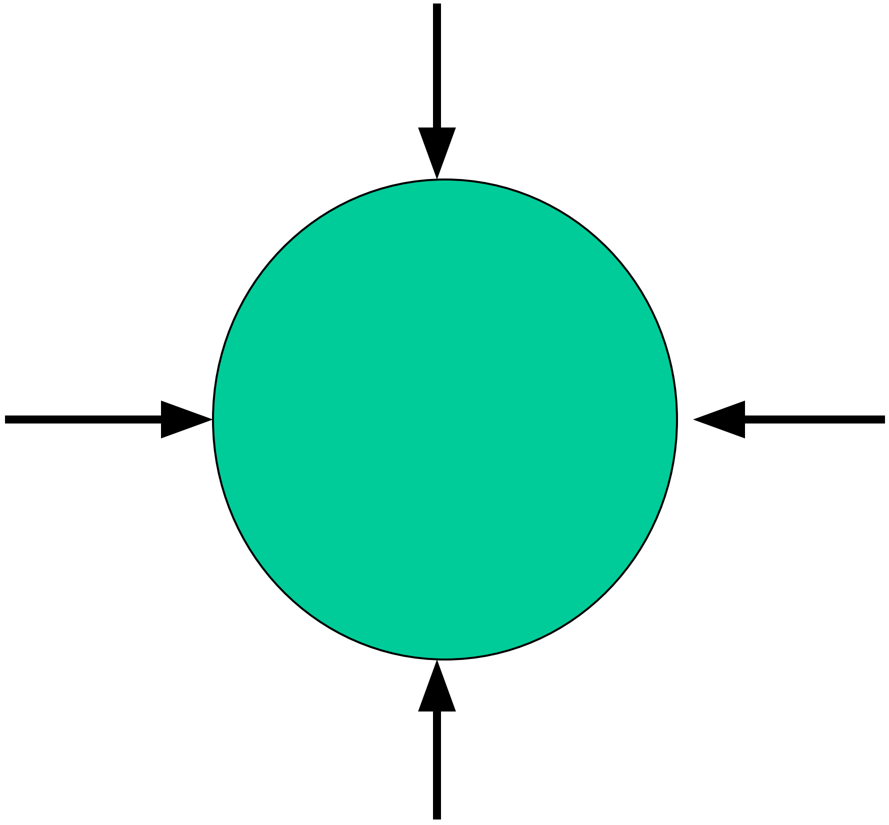


← photons are responsible for creating the electromagnetic field; they are the force carriers of the electromagnetic forces.

Fields

- I'll soon define a quantity that I will call an electric field.
- But first, I'm going to talk about a ***gravitational field*** (for the earth)
- Let me define the Earth's gravitational field:
  - It's a vector quantity that everywhere points to the center of the earth;
  - let R be the distance from the center of the earth;
  - at the earth's surface, $R = R_{earth}$ and $|Field| = g = 9.8$ N/kg

$$\vec{Field} = \frac{GM_{earth}}{R^2}$$

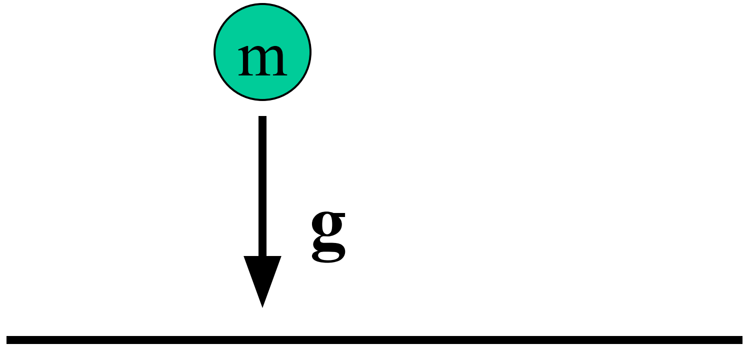


Force due to a gravitational field

- Suppose I put a test mass m at the earth's surface.
- It experiences a gravitational field **g**
- I can calculate the force experienced by m as

$$\mathbf{F} = m\,\mathbf{g}$$

- No matter what m is, if I know the field **g**, I can calculate the force on m.



In fact, I can use m to measure the value of **g** anywhere:

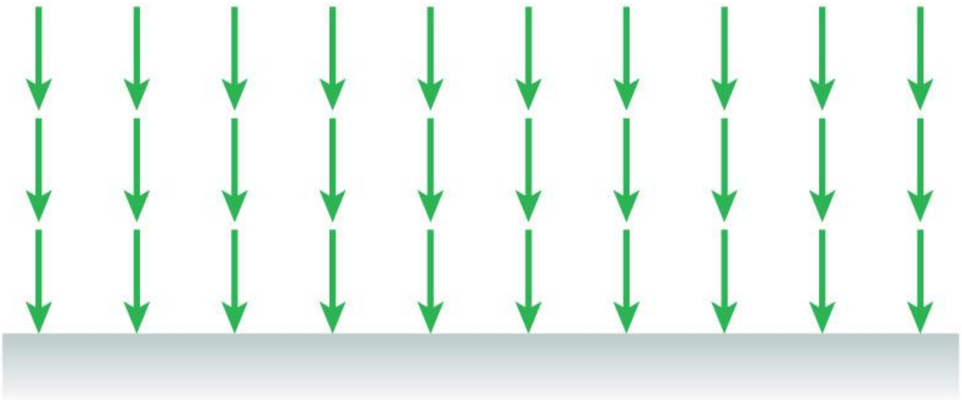
$$\mathbf{g} = \mathbf{F}/m$$

(boldface symbols are vectors)

Force due to a gravitational field

- At the earth's surface the field is fairly uniform both in direction and magnitude.
- But you may be wondering?
- **How can I determine my local values of gravitational acceleration and altitude?**
- The variation in the value of **g** across the earth's surface is about 0.5% due to latitude, plus a change of approximately 0.003% per 100 m altitude. Local topography and tidal forces also can have small effects

$\vec{g} = (9.8\ \mathrm{m/s^2}, \text{down})$ at all points

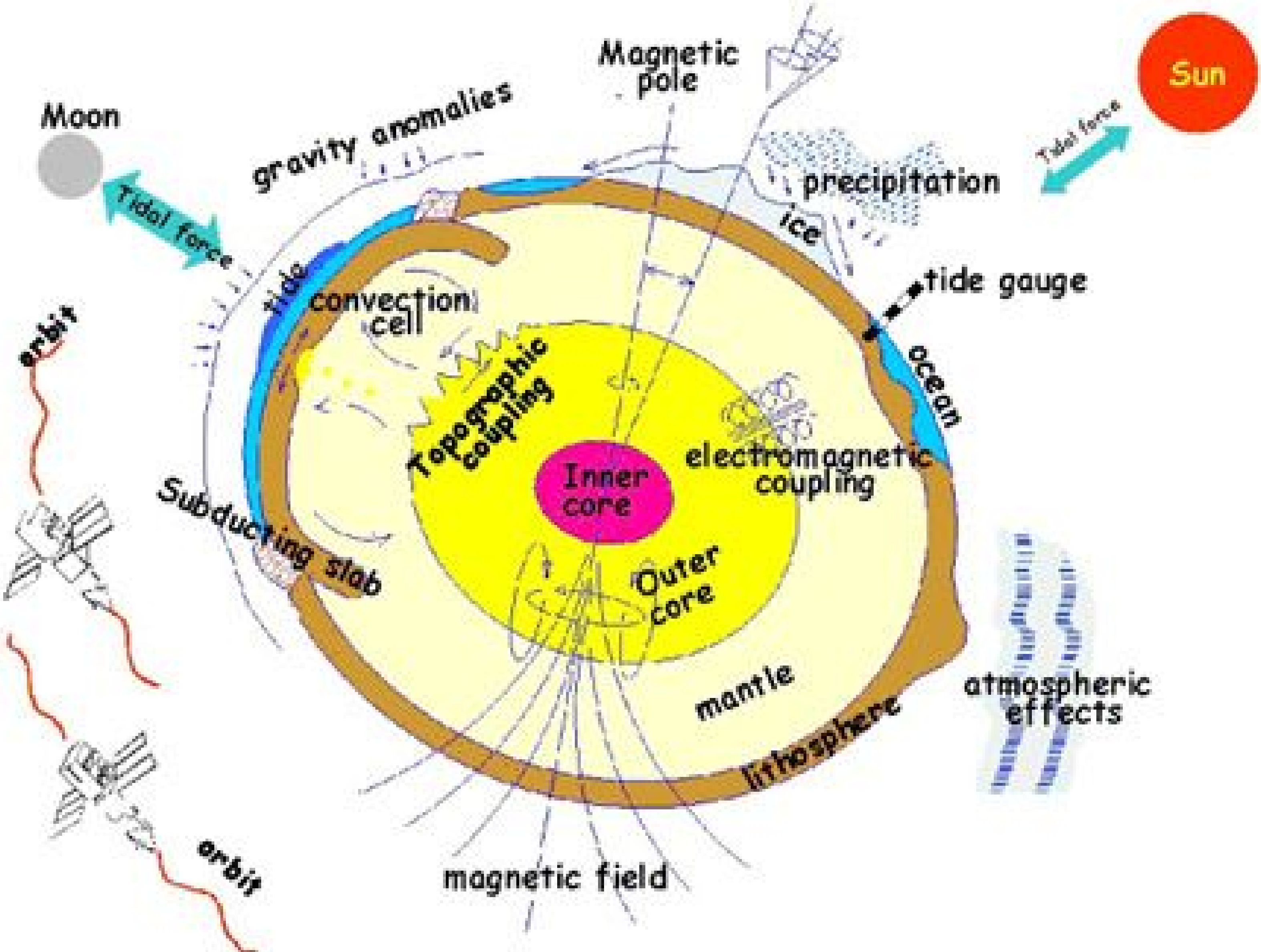


More accurately,

$$g = 9.780\,318\,4\,(1 + A \sin^2 L - B \sin^2 2L) - 3.086 \times 10^{-6}\, H$$

A=0.005 302 4 ; B=0.000 005 9 ;
L=latitude ;
H=height in metres above sea level

Effects on Earth's gravity



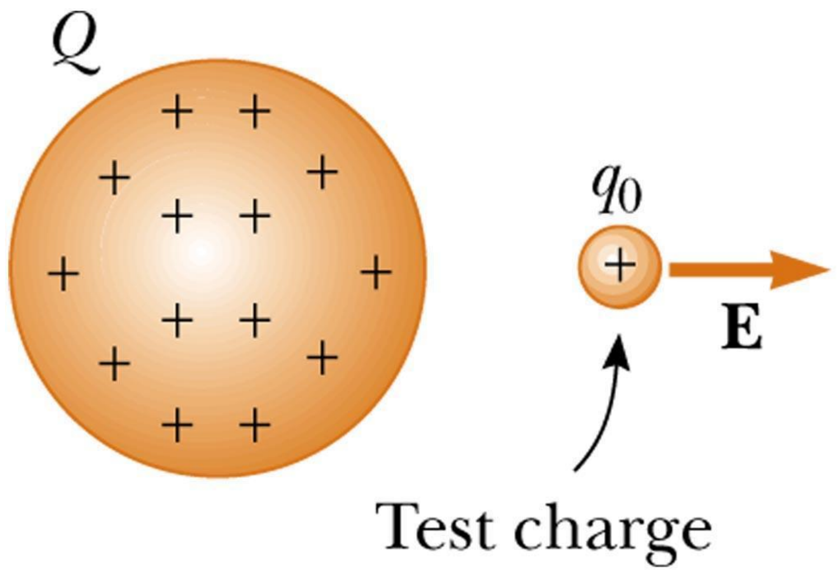
Spoiler alert

The tidal wave on the water planet in the movie Interstellar was caused by the proximity of a nearby black hole (and thus large tidal forces). However, the fact that the water seems to be 2 feet deep kind of negates that.

THE ELECTRIC FIELD

Q = source of **E** ;
q_0 = a small test charge located at **r** ;
Definition of the field: $\mathbf{E(r)} = \mathbf{F}/q_0$;
Important: E is a vector (like F).

- Now let's consider the idea of an electric field .
- I put a positive test charge q_o at some point in space and then use the force on this test charge to measure the electric field due to a another charge Q.
- Now, here's the tricky part:
  - the electric field is present at the position of the test charge q_o , whether or not q_o is there ;
  - in fact, the electric field is everywhere (just as the gravitational field was) ;
  - the force on the test charge q_o is just a convenient way of measuring the field.



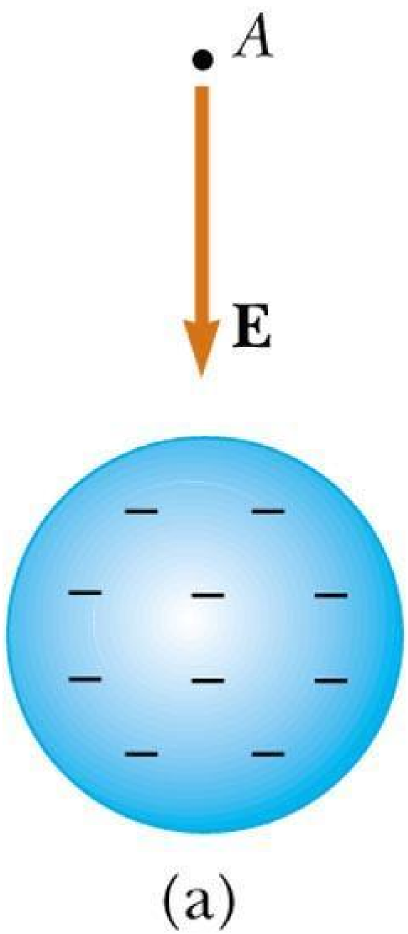
Force is a vector, so is the electric field. Since we made our test charge positive, the field is in the same direction as the force.

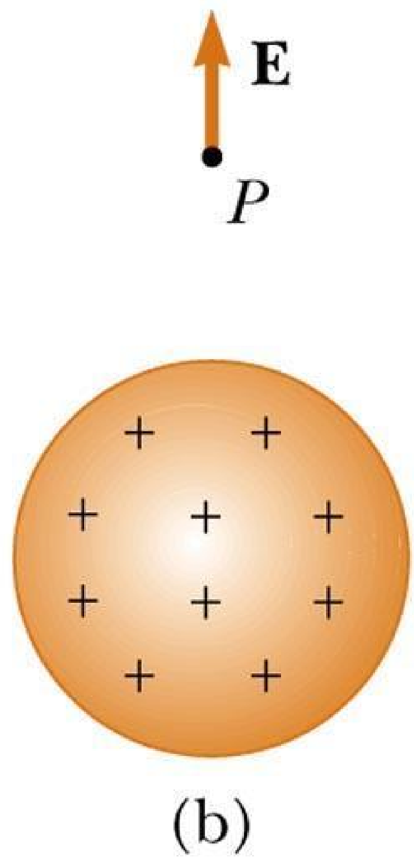
Electric Fields

Put a positive test charge q_o at the point A;

the force on q_o would be directed toward the negative charge distribution;

so that's the direction of the electric field from the negative charge distribution.



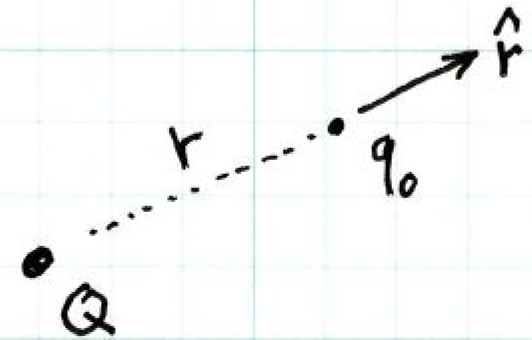


Put a positive test charge q_o at the point P;

the force on q_o would be directed away from the positive charge distribution;

so that's the direction of the electric field from the positive charge distribution.

ELECTRIC FIELD DUE TO A POINT CHARGE



The source of the electric field = a point with charge Q.

q_0 = a small positive test charge, located at **r** with respect to Q.

The force on q_0 (Coulomb force) is

$$\vec{F}_{\text{on } q_0} = \frac{1}{4\pi\epsilon_0} \frac{q_0 Q}{r^2} \hat{r}$$

The electric field at **r** is, by definition,

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$$

<u>Now forget about the test charge</u>. The electric field is present even if there is no test charge. The test charge is just a way to measure **E(r)**.

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$$

ELECTRIC FIELD DUE TO TWO CHARGES