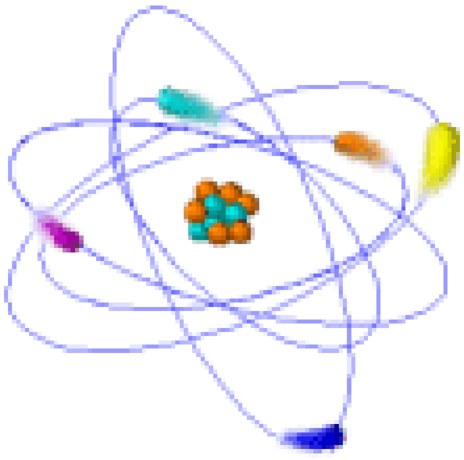
PHYS 2140

Physics for Students of Science and Engineering
PART II: ELECTRONS AND PHOTONS
Summer Semester 2015
Victor Karpov

Syllabus

1. **Check out the syllabus carefully: the schedule of lectures, quizzes and exams, the grading system, and the homework.**
2. ***This is all also on the Physics 2140 web site.***
3. **Also be sure you know the time and place of your *lab section*.**
4. **Buy lab manual from UT store**

Web site



<http://astro1.panet.utoledo.edu/~vkarpov/Physics-2140.html>

The Daily Quizzes

- Similar system as used in 2130.
- Daily quizzes... sometime
- Encourage attendance, interaction, feedback.
- Research shows these things are good!

Homework

- **For tomorrow:**
  - **Ch. 21 Questions 1,2; Problems 2,7,13,65**

What is physics?

- **The structure of the physical world.**
  - **What basic units are things made of?**
  - **The fundamental particles**
    - **Quarks, leptons, gluons, photons, gravitons**
- **The laws of nature.**
  - **How do these basic units behave?**
  - **The fundamental interactions**
    - **Gravitational, Electromagnetic, Nuclear**

This Semester: 4-week segments

1. **Electric Charges and Fields**

   Chs. 21-25

2. **Electrodynamics**

   Chs 26-32

3. **Optics and Relativity**

   Chs 33-37

4. **Quantum Physics**

   Chs 38-44

A World of Electric Charge

- The world is made of charged particles
- The common ones are
  - **The proton:** Charge $\mathbf{Q_p = +e}$
  - **The electron:** Charge $\mathbf{Q_e = -e}$
  - **The neutron:** Charge $\mathbf{Q_n = 0}$
- There is also **the photon:**
  - Photons have zero charge, but they interact with the charges of the others.

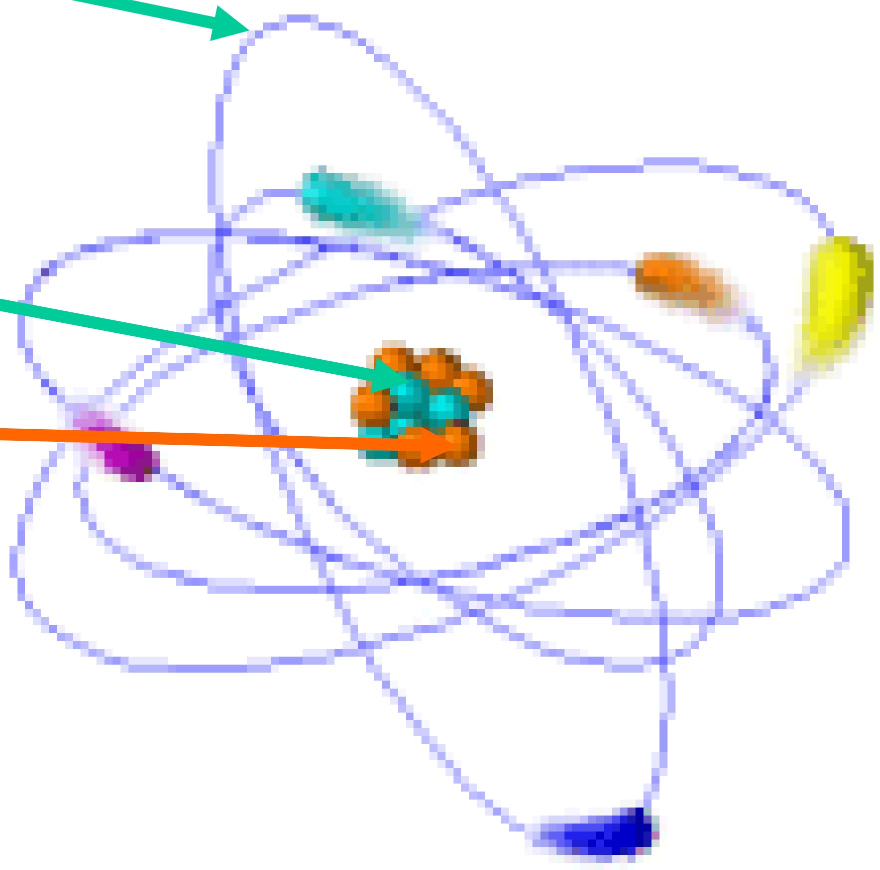
Atoms

Electrons

Nucleus

Protons

Neutrons



Atomic number and mass number

- **Z** = ***atomic number*** = no. of e's = no. of p's
  (so Q=0 for a neutral atom)
- **A** = ***mass number***
  = no. of protons + no. of neutrons
  ($m_p = m_n >> m_e$)
- N_A = Avagadro's number = $\mathbf{6 \times 10^{23}}$
  (number of atoms in one ***mole***)

N_A is defined so that the mass of N_A atoms is A grams

Example

Two isotopes of uranium:

U_{235} ($^{235}U_{92}$) has Z=92, A=235
(92p's, 92e's, 143n's)

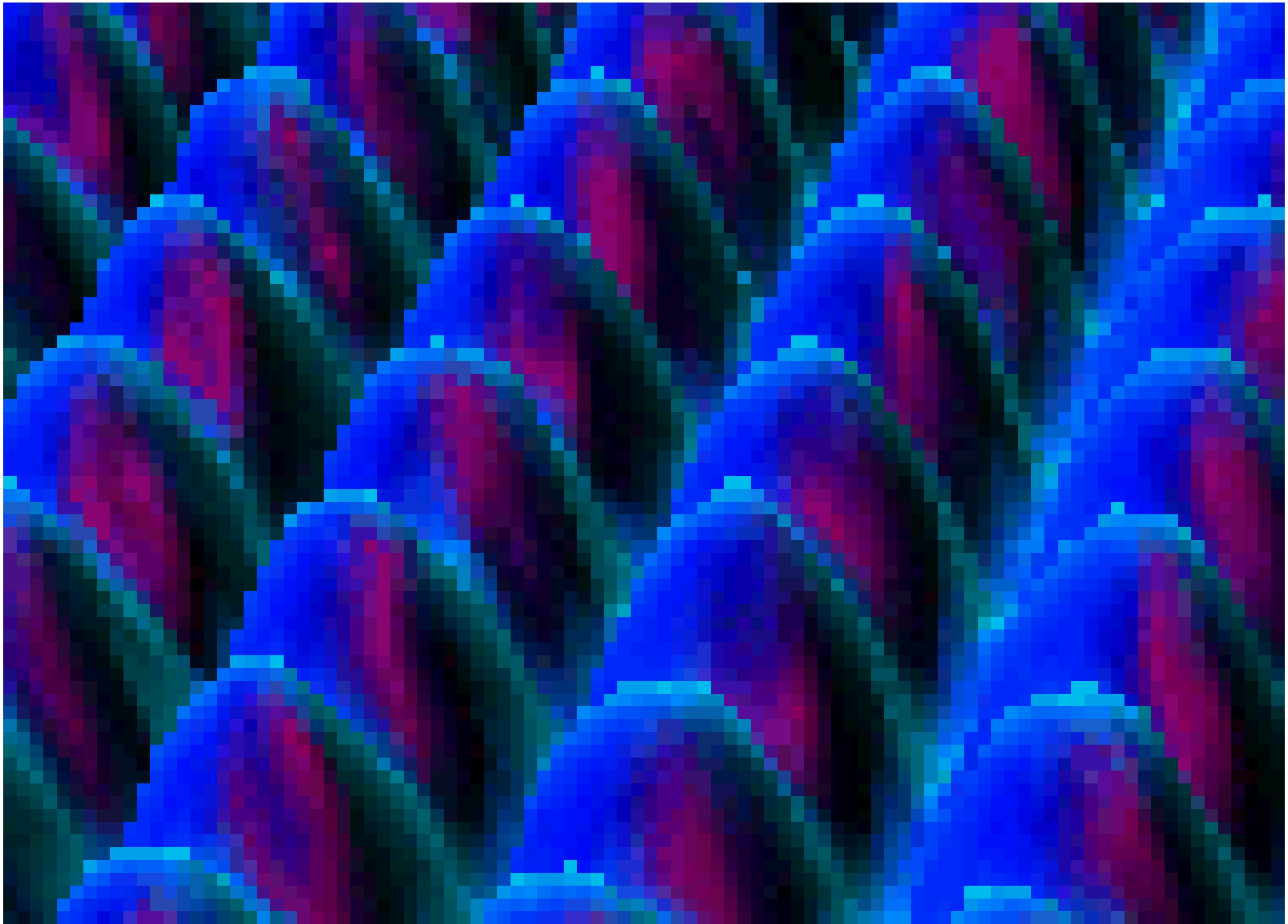
U_{238} ($^{238}U_{92}$) has Z=92, A=238
(92p's, 92e's, 146n's)

Question: How many atoms in 1 kg of U_{235}?

Answer: One mole is 235 grams, so 1 kg is 1000/235 = 4.26 moles. The number of atoms in a mole is $N_A = 6 \times 10^{23}$ so the answer is

$$\mathbf{4.26 \times 6 \times 10^{23} = 2.6 \times 10^{24}} \quad \text{atoms}$$

Surface of a pure metal showing individual atoms.



Chapter 21

- **Electric Charge**
- **Coulomb's Law**
- **Review**
  - **Powers of Ten**
  - **Vector Calculations**
  - **Atoms and Electrons**

I. Electric Charge

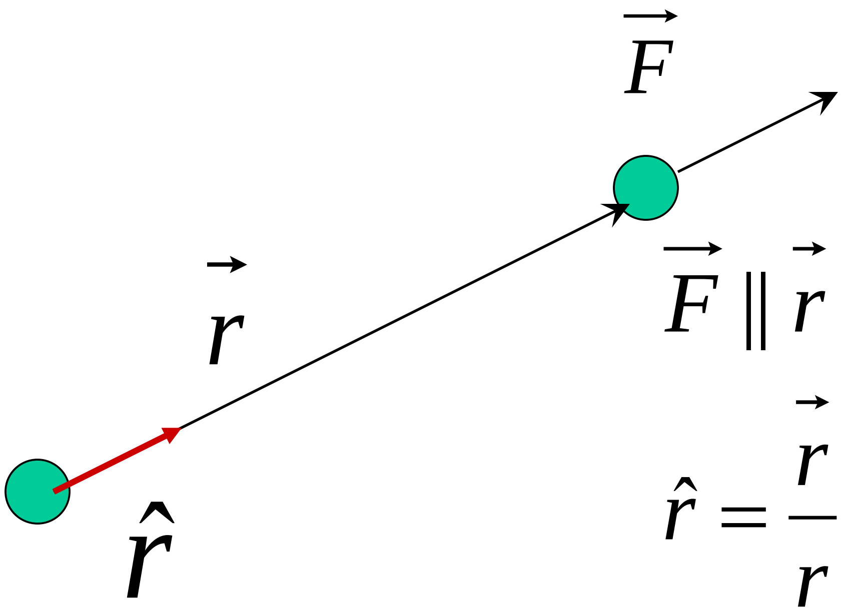
- **Two kinds: positive and negative**
- **Matter is made of charged particles: protons, electrons, atoms, molecules**
- **Charge is *conserved* and *quantized***
- **The elementary charge: $e = 1.6 \times 10^{-19}$ C.**
- **Electric current -- the rate of flow of charge**
- **Conducting and insulating materials**

II. Coulomb's Law

$$F = k\frac{Q_1 Q_2}{r^2}$$

- Inverse square law, attraction and repulsion
- SI units: Coulomb and Ampere
- The Coulomb constant: k = 9 x 10^9 SI units.

III. Vector notation



$$\vec{F} \parallel \vec{r}$$

$$\hat{r} = \frac{\vec{r}}{r} \quad \text{unit vector}$$

$$\vec{F} \parallel \hat{r}$$

$$\vec{F} = F\hat{r}$$

III. Vector Notation

$$\vec{F} = k \frac{Q_1 Q_2 \vec{r}}{r^3} = k \frac{Q_1 Q_2 \hat{r}}{r^2}$$

If two forces act on a body, then the net force is the **vector sum:**

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

BUT remember that the **magnitudes** may **NOT** add:

$\vec{A} = \vec{B} + \vec{C}$ does **not** mean that A = B + C

Chapter 21 Homework

- Read Chapter 21
  - Note Checkpoints 3,4
  - Do Questions 1,2 – not graded
  - Do Problems 2, 7, 13, 65

Syllabus

- **Does everyone have a syllabus?**
- **Do you know the time and place of your *lab section*?**
- **Any questions about the course?**

Notes about quizzes and exams

- Do the powers of 10 in your head.
- Use only one or two significant figures – that's enough to show you have the basic principles right.

For example $k \approx 9 \times 10^{9} \approx 10^{10}$ SI units

Example Problem

Two charges are separated by 3 meters. If each charge is 2 microcoulombs, what is the force by one charge on the other?

Solution

$$Q = 2\mu C = 2\times 10^{-6} C$$

$$F = k\frac{Q^2}{r^2} = \frac{9\times 10^9 \times (2\times 10^{-6})^2}{3^2}$$

$$F = \frac{9\times 4\times 10^{-3}}{9} = \underline{4\times 10^{-3} N}$$

Chapter 21: Charge and Coulomb's Law

If you don't yet have syllabus and homework schedules please pick them up now.

Better find on the web

Chapter 21 Homework

- **Find 2140 homepage (physics.utoledo.edu)**
- **Read Chapter 21**
  - **Note Checkpoints 3,4**
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I. Electric Charge

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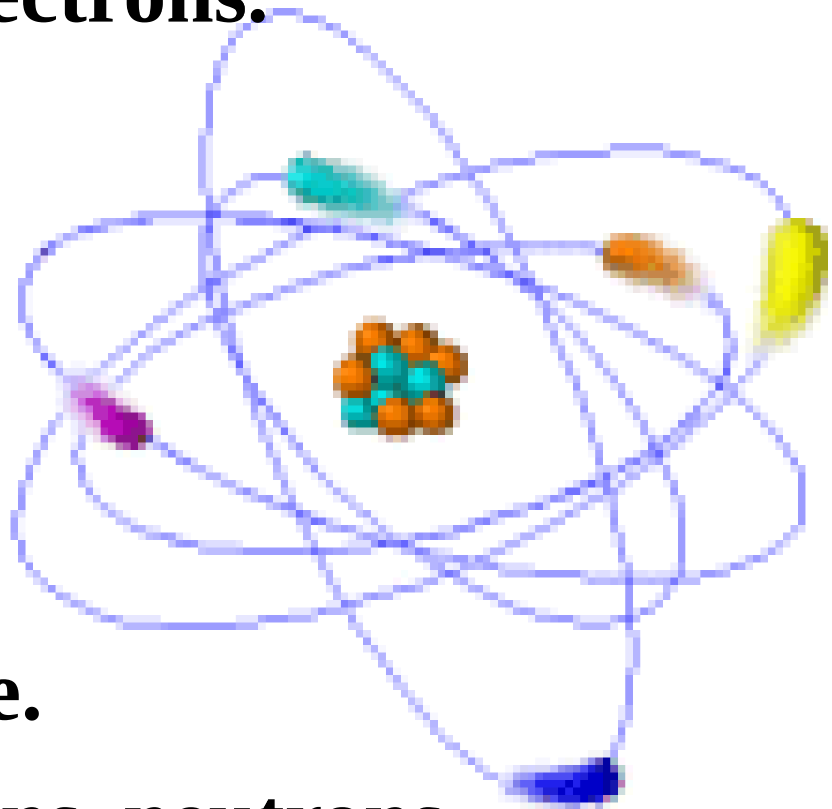
For example $k = 9 \times 10^9$ **SI units**

The quantum of charge

The world is made of atoms, which are made of protons, neutrons and electrons.



- **Proton has charge +e.**
- **Electron has charge –e.**
- **Neutron has charge 0.**

Atom is mostly empty space.

Tiny nucleus contains protons, neutrons.

Fundamental quantum of charge: $\mathbf{e = 1.60 \times 10^{-19}\ C}$

Moving Charge

- **I can charge an object by adding or removing electrons.**
- **When I comb my cat, I move electrons from the fur to the rubber comb, leaving the cat with a net *positive* charge, and the comb with a *negative* charge.**
- ***Charge conservation* means that, if both cat and comb were originally neutral, then**

$$Q_{cat} + Q_{comb} = 0$$

Atomic number and mass number

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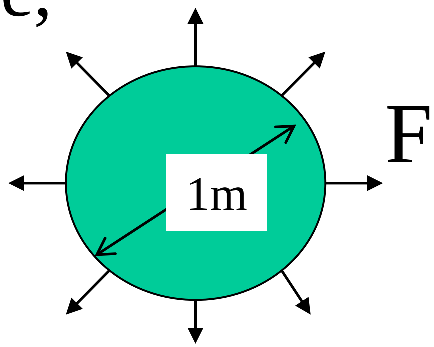
$$4.26 \times 6 \times 10^{23} = 2.6 \times 10^{24} \quad \text{atoms}$$

Another example

- Estimate the force on a person who lost electrons from 1 gram of his/her body?



- Model body with a ~1 m^3 water sphere,
- 1 mole of H_20 is 18g.
- 1 g has $n=N_A/18 \sim 10^{22}$ atoms
- Electric charge $Q=ne \sim 10^3$ C
- Force $F=kQ^2/r^2 \sim 10^{10} \times (10^3)^2 / 1^2=10^{16}$ N

Huge! Electrostatic forces are strong.

Coulomb's Law: Action at a Distance?

- One charged object exerts a force on another.
- Like charges repel, unlike charges attract.
- How can a force be exerted at a distance?
- Next chapter: the electric field.

The inverse square law

- True for both electricity and gravity! Why?
- Because space is three-dimensional.
- $F \propto 1/r^2$
- If $r \rightarrow 2r$ then $F \rightarrow F/4$
- The force is inversely proportional to the square of the distance

The Coulomb Law Constants

Coulomb's experiment gives $F = kQ_1Q_2/R^2$

and determines the ***electrostatic constant***

$$\mathbf{k = 8.99 \times 10^9 \approx 9 \times 10^9} \quad \text{SI units}$$

This is often written as $k = \dfrac{1}{(4\pi\varepsilon_0)}$

with the ***permittivity constant*** having the value

$$\varepsilon_0 = 8.85 \times 10^{-12} \quad \text{SI units}$$

Example 1

Two charges are separated by 3 meters. If each charge is 2 microcoulombs, what is the force by one charge on the other?

Solution

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$$F = k\frac{Q^2}{r^2} = \frac{9\times 10^{9}\times (2\times 10^{-6})^2}{3^2}$$

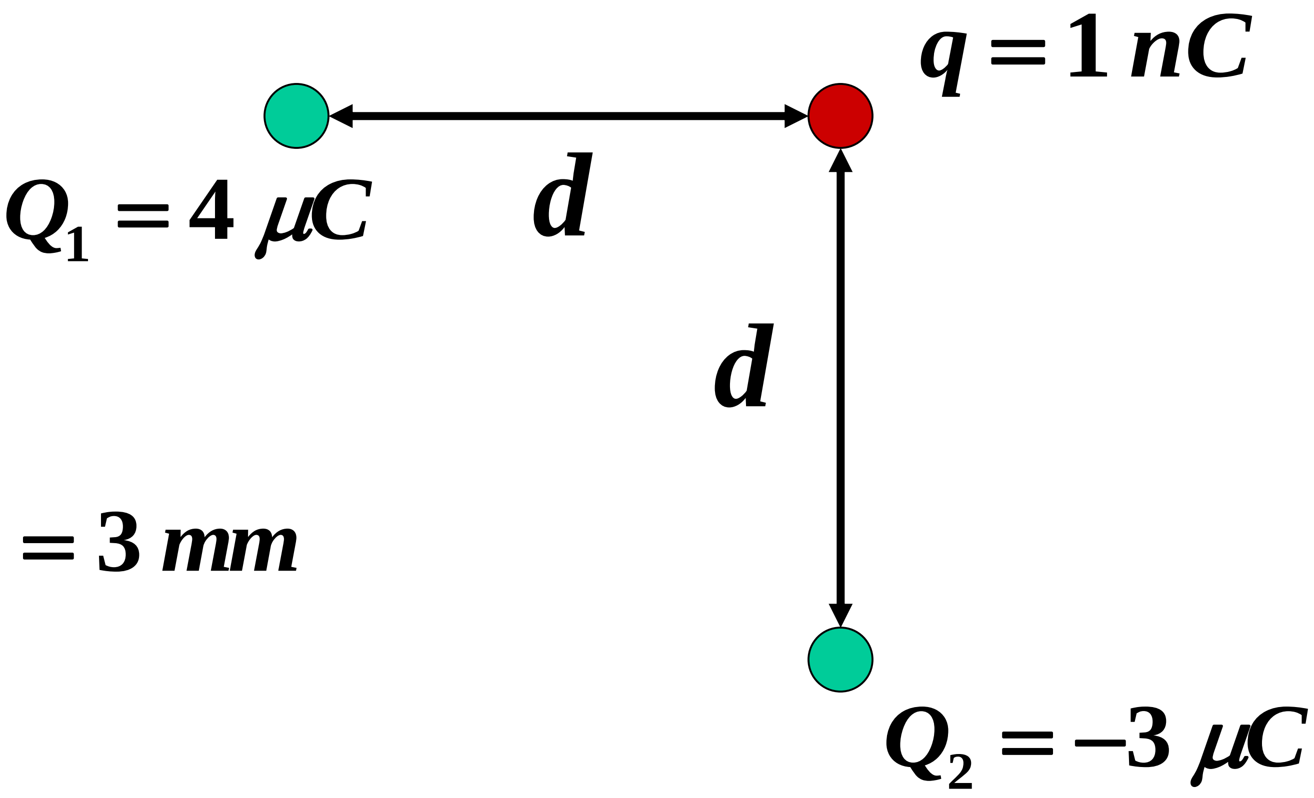
$$F = \frac{9\times 4\times 10^{-3}}{9} = \underline{4\times 10^{-3} N}$$

Two charges are separated by 2 m and repel each other with a force of 20 N. If they are moved to a separation of 4 m, what will be the repulsive force?

1. 5 N
2. 10 N
3. 20 N
4. 40 N
5. 80 N

Example 2

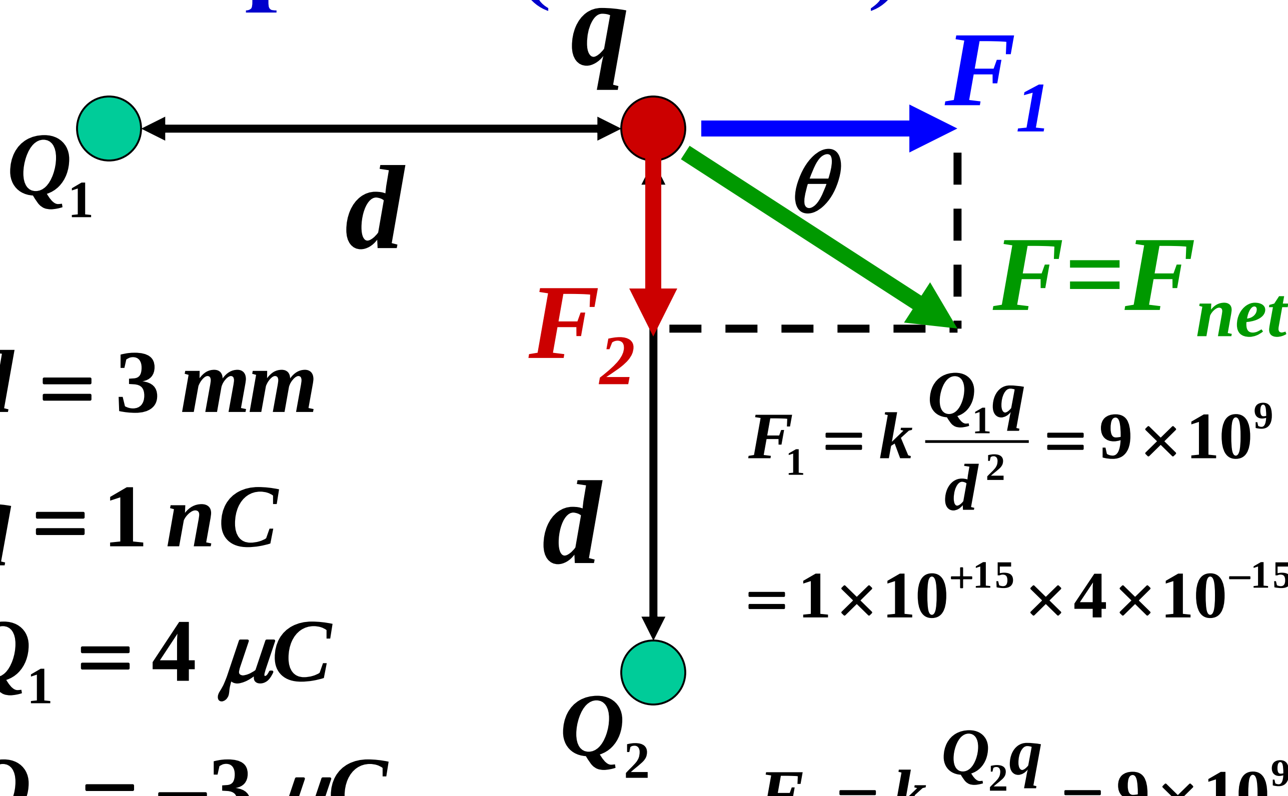
What is the net force on the charge q due to the charges Q_1 and Q_2 placed as shown?



$d = 3\ mm$

Example 2 (cont'd)

What is the net force on q?



$$d = 3\ mm$$

$$q = 1\ nC$$

$$Q_1 = 4\ \mu C$$

$$Q_2 = -3\ \mu C$$

$$F_1 = k\frac{Q_1 q}{d^2} = 9\times10^9\,\frac{(4\times10^{-6})(1\times10^{-9})}{(3\times10^{-3})^2}$$

$$= 1\times10^{+15}\times4\times10^{-15}\,N = \underline{4\ N}$$

$$F_2 = k\frac{Q_2 q}{d^2} = 9\times10^9\,\frac{(3\times10^{-6})(1\times10^{-9})}{(3\times10^{-3})^2}$$

$$= 1\times10^{+15}\times3\times10^{-15}\,N = \underline{3\ N}$$

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

$$F = \sqrt{F_1^{\ 2} + F_2^{\ 2}} = \sqrt{3^2 + 4^2} = \underline{5\ N}$$

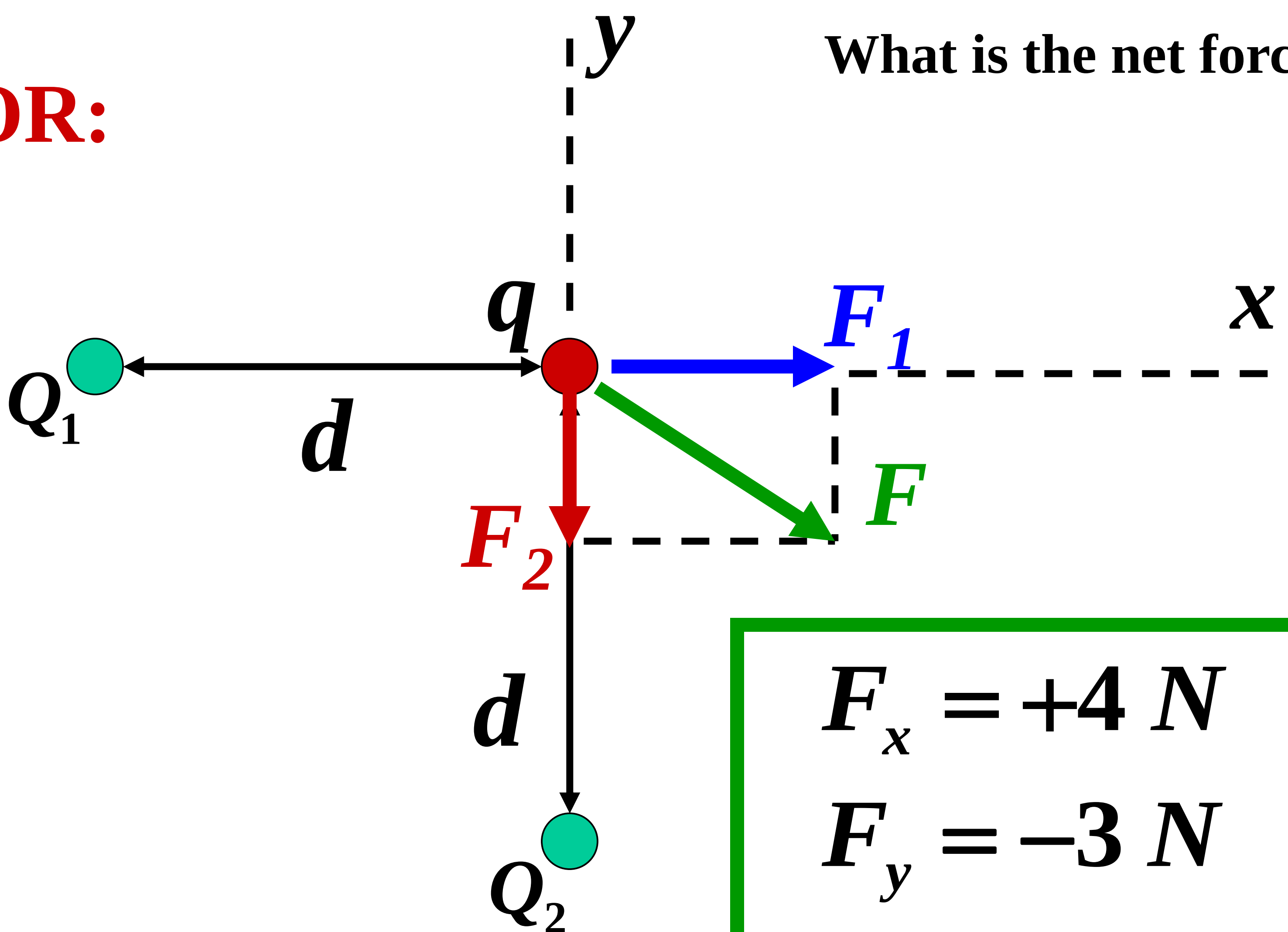
$$\tan\theta = 3/4$$

$$\theta = 37^\circ$$

Example 2 (cont'd)

OR:

What is the net force on *q*?



$$F_x = +4\ N$$

$$F_y = -3\ N$$