1Electromagnetism

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Review: Chapter 12, Vol. I, *Characteristics of Force*

1–1Electrical forces

$F_E >>> F_G$.

Consider a force like gravitation which varies predominantly inversely as the square of the distance, but which is about a *billion-billion-billion-billion* times stronger. And with another difference. There are two kinds of "matter," which we can call positive and negative. Like kinds repel and unlike kinds attract—unlike gravity where there is only attraction. What would happen?

A bunch of positives would repel with an enormous force and spread out in all directions. A bunch of negatives would do the same. But an evenly mixed bunch of positives and negatives would do something completely different. The opposite pieces would be pulled together by the enormous attractions. The net result would be that the terrific forces would balance themselves out almost perfectly, by forming tight, fine mixtures of the positive and the negative, and between two separate bunches of such mixtures there would be practically no attraction or repulsion at all.

There is such a force: the electrical force. And all matter is a mixture of positive protons and negative electrons which are attracting and repelling with this great force. So perfect is the balance, however, that when you stand near someone else you don't feel any force at all. If there were even a little bit of unbalance you would know it. If you were standing at arm's length from someone and each of you had *one percent* more electrons than protons, the repelling force would be incredible. How great? Enough to lift the Empire State Building? No! To lift Mount Everest? No! The repulsion would be enough to lift a "weight" equal to that of the entire earth!

With such enormous forces so perfectly balanced in this intimate mixture, it is not hard to understand that matter, trying to keep its positive and negative charges in the finest balance, can have a great stiffness and strength. The Empire State Building, for example, swings less than one inch in the wind because the electrical forces hold every electron and proton more or less in its proper place. On the other hand, if we look at matter on a scale small enough that we see only a few atoms, any small piece will not, usually, have an equal number of positive and negative charges, and so there will be strong residual electrical forces. Even when there are equal numbers of both charges in two neighboring small pieces, there may still be large net electrical forces because the forces between individual charges vary inversely as the square of the distance. A net force can arise if a negative charge of one piece is closer to the positive than to the negative charges of the other piece. The attractive forces can then be larger than the repulsive ones and there can be a net attraction between two small pieces with no excess charges. The force that holds the atoms together, and the chemical forces that hold molecules together, are really electrical forces acting in regions where the balance of charge is not perfect, or where the distances are very small.

You know, of course, that atoms are made with positive protons in the nucleus and with electrons outside. You may ask: "If this electrical force is so terrific, why don't the protons and electrons just get on top of each other? If they want to be in an intimate mixture, why isn't it still more intimate?" The answer has to do with the quantum effects. If we try to confine our electrons in a region that is very close to the protons, then according to the uncertainty principle they must have some mean square momentum which is larger the more we try to confine them. It is this motion, required by the laws of quantum mechanics, that keeps the electrical attraction from bringing the charges any closer together.

There is another question: "What holds the nucleus together"? In a nucleus there are several protons, all of which are positive. Why don't they push themselves apart? It turns out that in nuclei there are, in addition to electrical forces, nonelectrical forces, called nuclear forces, which are greater than the electrical forces and which are able to hold the protons together in spite of the electrical repulsion. The nuclear forces, however, have a short range—their force falls off much more rapidly than $1/r^2$. And this has an important consequence. If a nucleus has too many protons in it, it gets too big, and it will not stay together. An example is uranium, with 92 protons. The nuclear forces act mainly between each proton (or neutron) and its nearest neighbor, while the electrical forces act over larger distances, giving a repulsion between each proton and all of the others in the nucleus. The more protons in a nucleus, the stronger is the electrical repulsion, until, as in the case of uranium, the balance is so delicate that the nucleus is almost ready to fly apart from the repulsive electrical force. If such a nucleus is just "tapped" lightly (as can be done by sending in a slow neutron), it breaks into two pieces, each with positive charge, and these pieces fly apart by electrical repulsion. The energy which is liberated is the energy of the atomic bomb. This energy is usually called "nuclear" energy, but it is really "electrical" energy released when electrical forces have overcome the attractive nuclear forces.

Lower case Greek letters
and commonly used capitals

α	alpha	ι	iota	ρ	rho
β	beta	κ	kappa	σ Σ	sigma
γ Γ	gamma	λ Λ	lambda	τ	tau
δ Δ	delta	μ	mu	υ Υ	upsilon
ϵ	epsilon	ν	nu	ϕ Φ	phi
ζ	zeta	ξ Ξ	xi (ksi)	χ	chi (khi)
η	eta	o	omicron	ψ Ψ	psi
θ Θ	theta	π Π	pi	ω Ω	omega

We may ask, finally, what holds a negatively charged electron together (since it has no nuclear forces). If an electron is all made of one kind of substance, each part should repel the other parts. Why, then, doesn't it fly apart? But does the electron have "parts"? Perhaps we should say that the electron is just a point and that electrical forces only act between *different* point charges, so that the electron does not act upon itself. Perhaps. All we can say is that the question of what holds the electron together has produced many difficulties in the attempts to form a complete theory of electromagnetism. The question has never been answered. We will entertain ourselves by discussing this subject some more in later chapters.

As we have seen, we should expect that it is a combination of electrical forces and quantum-mechanical effects that will determine the detailed structure of materials in bulk, and, therefore, their properties. Some materials are hard, some are soft. Some are electrical "conductors"—because their electrons are free to move about; others are "insulators"—because their electrons are held tightly to individual atoms. We shall consider later how some of these properties come about, but that is a very complicated subject, so we will begin by looking at the electrical forces only in simple situations. We begin by treating only the laws of electricity—including magnetism, which is really a part of the same subject.

We have said that the electrical force, like a gravitational force, decreases inversely as the square of the distance between charges. This relationship is called Coulomb's law. But it is not precisely true when charges are moving—the electrical forces depend also on the motions of the charges in a complicated way. One part of the force between moving charges we call the *magnetic* force. It is really one aspect of an electrical effect. That is why we call the subject "electromagnetism."

There is an important general principle that makes it possible to treat electromagnetic forces in a relatively simple way. We find, from experiment, that the force that acts on a particular charge—no matter how many other charges there are or how they are moving—depends only on the position of that particular charge, on the velocity of the charge, and on the amount of charge. We can write the force $\boldsymbol{F}$ on a charge q moving with a velocity $\boldsymbol{v}$ as

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}). \tag{1.1}$$

We call $\boldsymbol{E}$ the *electric field* and $\boldsymbol{B}$ the *magnetic field* at the location of the charge. The important thing is that the electrical forces from all the other charges in the universe can be summarized by giving just these two vectors. Their values will depend on *where* the charge is, and may change with *time*. Furthermore, if we replace that charge with another charge, the force on the new charge will be just in proportion to the amount of charge so long as all the rest of the charges in the world do not change their positions or motions. (In real situations, of course, each charge produces forces on all other charges in the neighborhood and may cause these other charges to move, and so in some cases the fields *can* change if we replace our particular charge by another.)

We know from Vol. I how to find the motion of a particle if we know the force on it. Equation (1.1) can be combined with the equation of motion to give

$$\frac{d}{dt}\left[\frac{m\boldsymbol{v}}{(1 - v^2/c^2)^{1/2}}\right] = \boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}). \tag{1.2}$$

So if $\boldsymbol{E}$ and $\boldsymbol{B}$ are given, we can find the motions. Now we need to know how the $\boldsymbol{E}$'s and $\boldsymbol{B}$'s are produced.

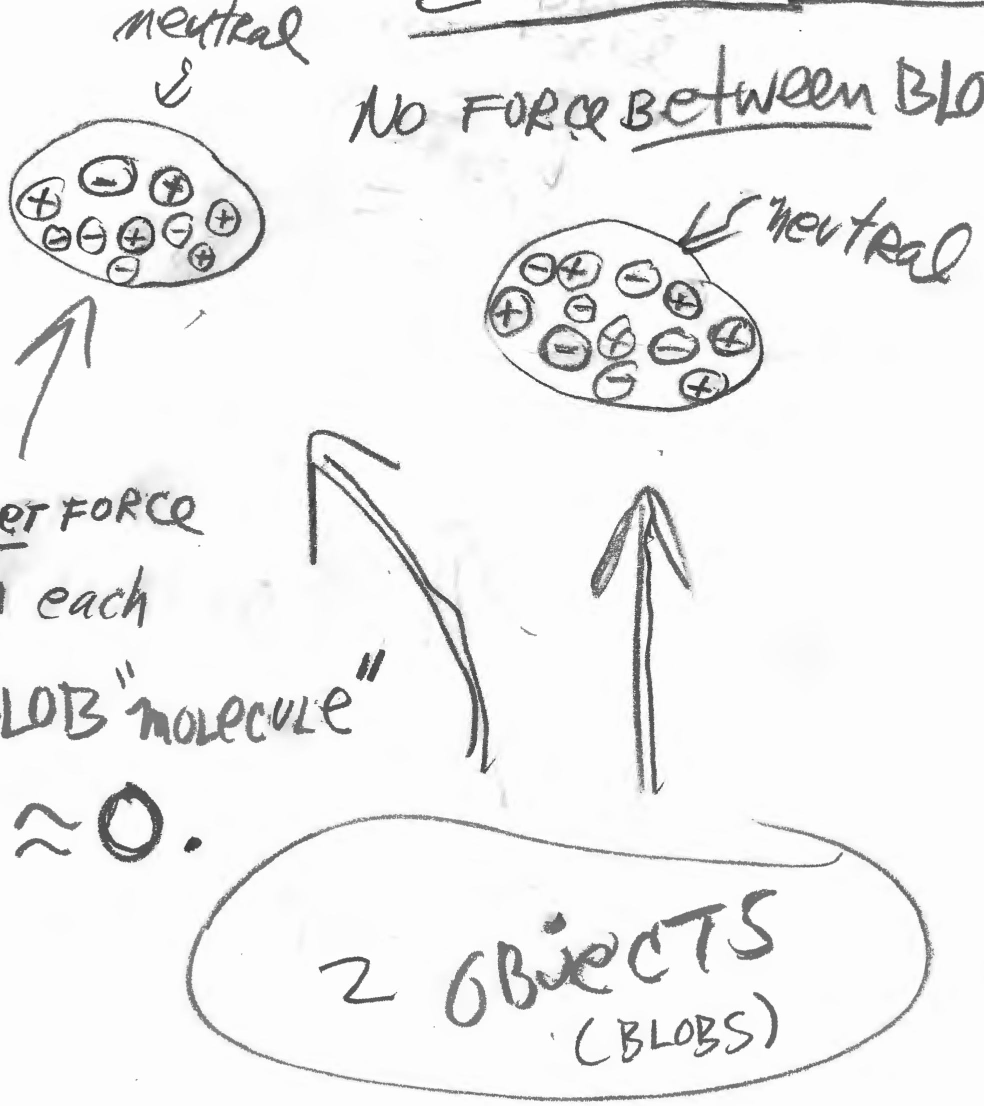
One of the most important simplifying principles about the way the fields are produced is this: Suppose a number of charges moving in some manner would produce a field $\boldsymbol{E}_1$, and another set of charges would produce $\boldsymbol{E}_2$. If both sets of charges are in place at the same time (keeping the same locations and motions they had when considered separately), then the field produced is just the sum

$$\boldsymbol{E} = \boldsymbol{E}_1 + \boldsymbol{E}_2. \tag{1.3}$$

This fact is called *the principle of superposition* of fields. It holds also for magnetic fields.

2 "Blobs" EXAMPLE:

No FORCE between Blobs



Inside blob: NET FORCE
on each
BLOB "molecule"
≈ 0.

See Feynman Lectures
Link: 1-1 Electrical
Forces

PHYSICS 4B 1-22-14 (Happy New Year)

CH. 21

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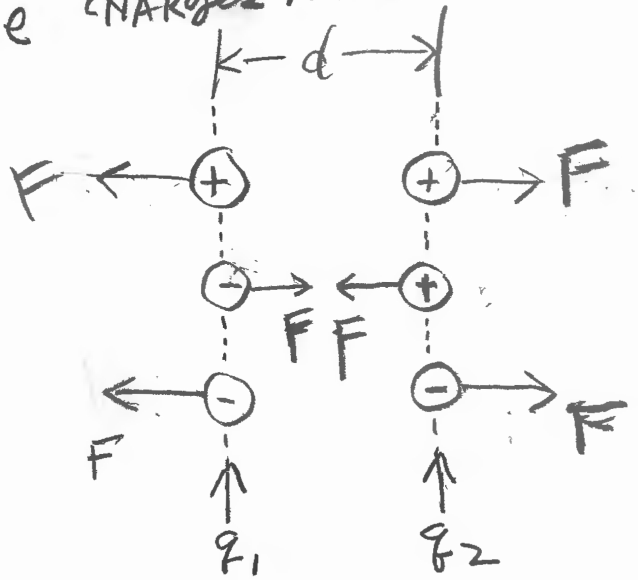
Like charges repel; unlike charges attract:



COULOMB'S LAW:

$$F = \frac{k \cdot |q_1 \cdot q_2|}{d^2}$$

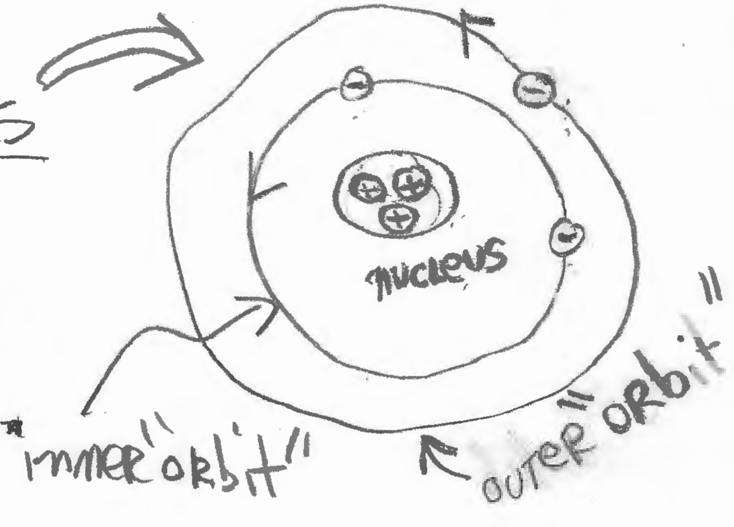
$$K \doteq 9\times10^9 \frac{N\cdot m^2}{C^2}$$

C = coulomb (charge unit)

Most objects are composed of equal ⊕ and ⊖ charges (neutral).

Atoms

See also example on gravity in hydrogen atom.

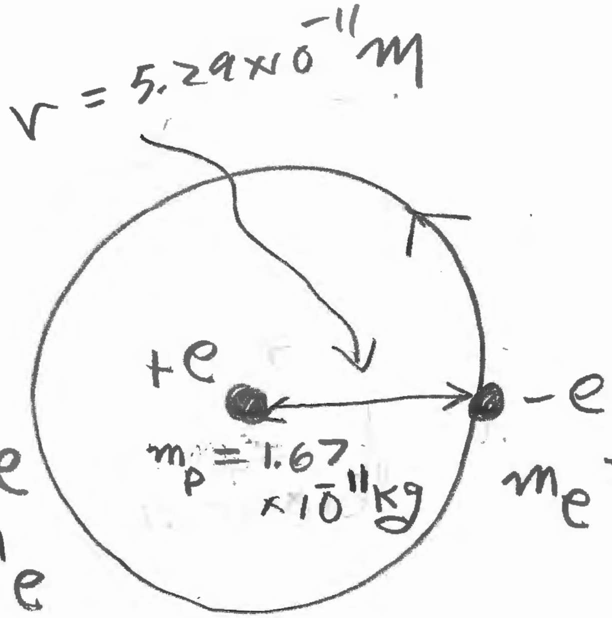


Lithium:

3 protons in nucleus.

3 "orbiting" electrons.

GRAVITY in a HYDROGEN ATOM:



$|q_1| = |q_2| = e$

$e = 1.60 \times 10^{-19}\ C$

$m_e = 9.11 \times 10^{-31}\ kg$

$m_p \approx 2000\, m_e$

$m_p >> m_e$

PROTON AT REST.

$$F_e = k \cdot \frac{|q_1 \cdot q_2|}{r^2} = \frac{ke^2}{r^2} \text{ and}$$

$$(\text{ch}13)\ F_g = G \cdot \frac{m_1 m_2}{r^2} = G\frac{m_e m_p}{r^2};$$

$$G = 6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}.$$

$$\frac{F_e}{F_g} = \frac{ke^2}{G m_e m_p} = \left(\frac{8.99 \times 10^{9}\ N \cdot m^2/C^2}{6.67 \times 10^{-11}\ N \cdot m^2/kg^2}\right) \times \frac{(1.60 \times 10^{-19}\ C)^2}{(9.11 \times 10^{-31}\ kg)(1.67 \times 10^{-27}\ kg)}$$

$$\boxed{\frac{F_e}{F_g} = 2.27 \times 10^{39}}$$

CONDUCTORS: "LOOSELY BOUND" OUTER valence electrons HOP FROM ATOM TO ATOM IN the METAL : ELECTRONS ARE mobile.

INSULATORS: electrons are TIGHTLY BOUND and don't TRAVEL inter- ATOMICALLY : RUBBER, PLASTICS, ETC.

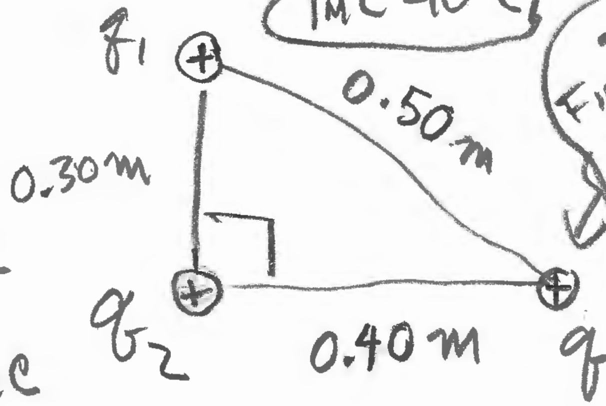
Example

$1\,\mu C = 10^{-6}\,C$

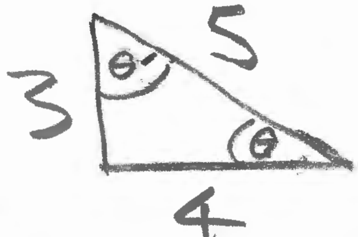
$q_1 = 2.0\,\mu C$

$q_2 = 2.0\,\mu C$

$q_3 = 4.0\,\mu C$



FIND NET FORCE ON q_3



$\theta = 37°$

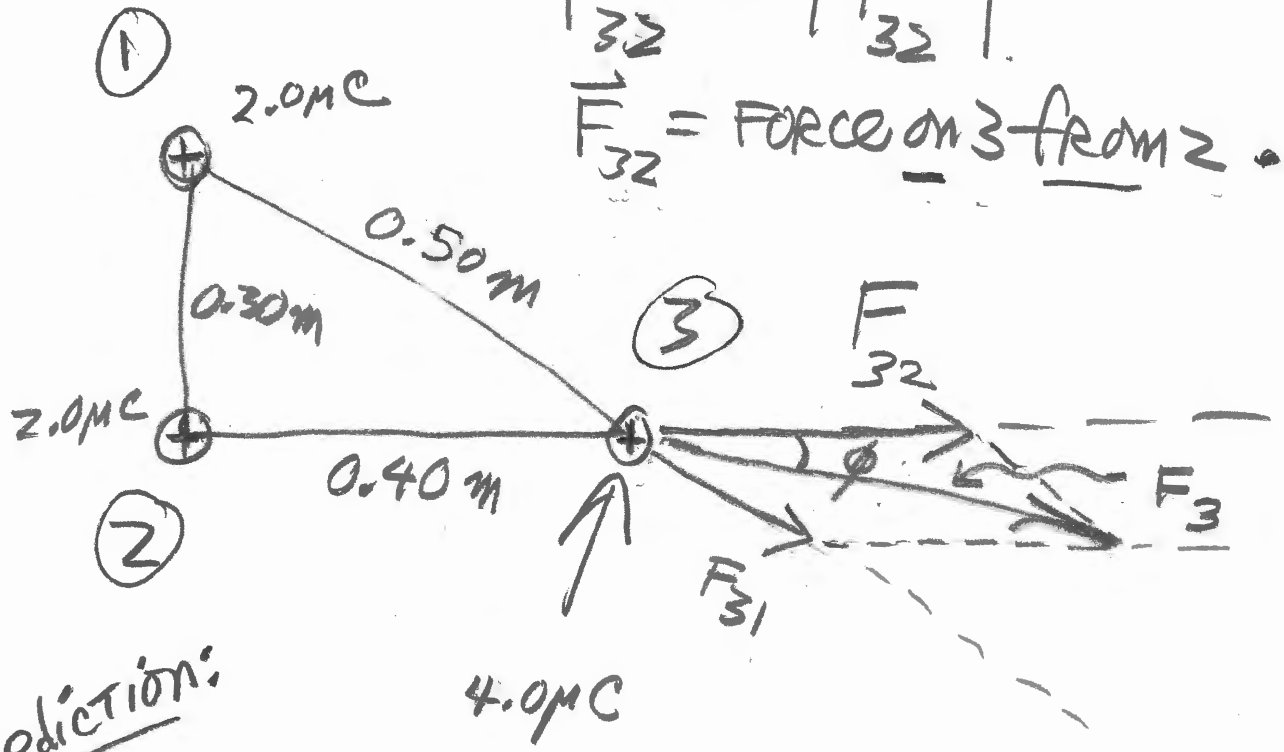
$\theta' = 53°$

$90°$

$\boxed{\vec{F}_3 = ?}$

$F_{32} = |\vec{F}_{32}|$

$\vec{F}_{32}$ = FORCE on 3 from 2.



prediction:

$F_{31} < F_{32}$

0.50 m > 0.40 m

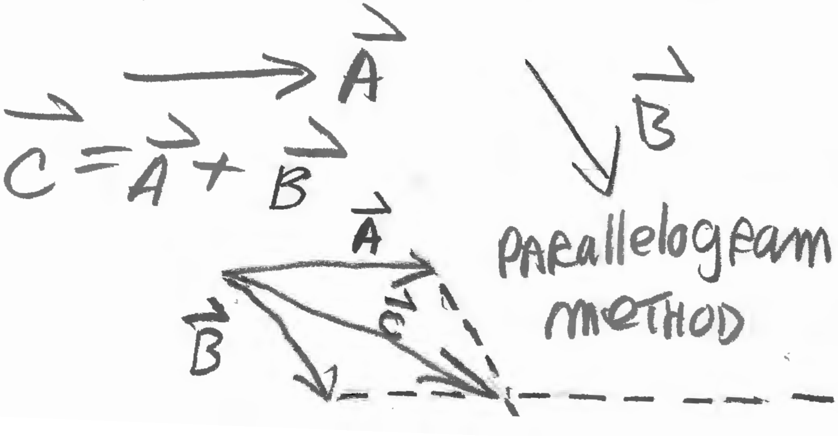
"Homework" Assignment:
FIND $\vec{F}_3$ using component method

$F_{3x} = F_{31x} + F_{32x}$

$F_{3y} = F_{31y} + F_{32y}$

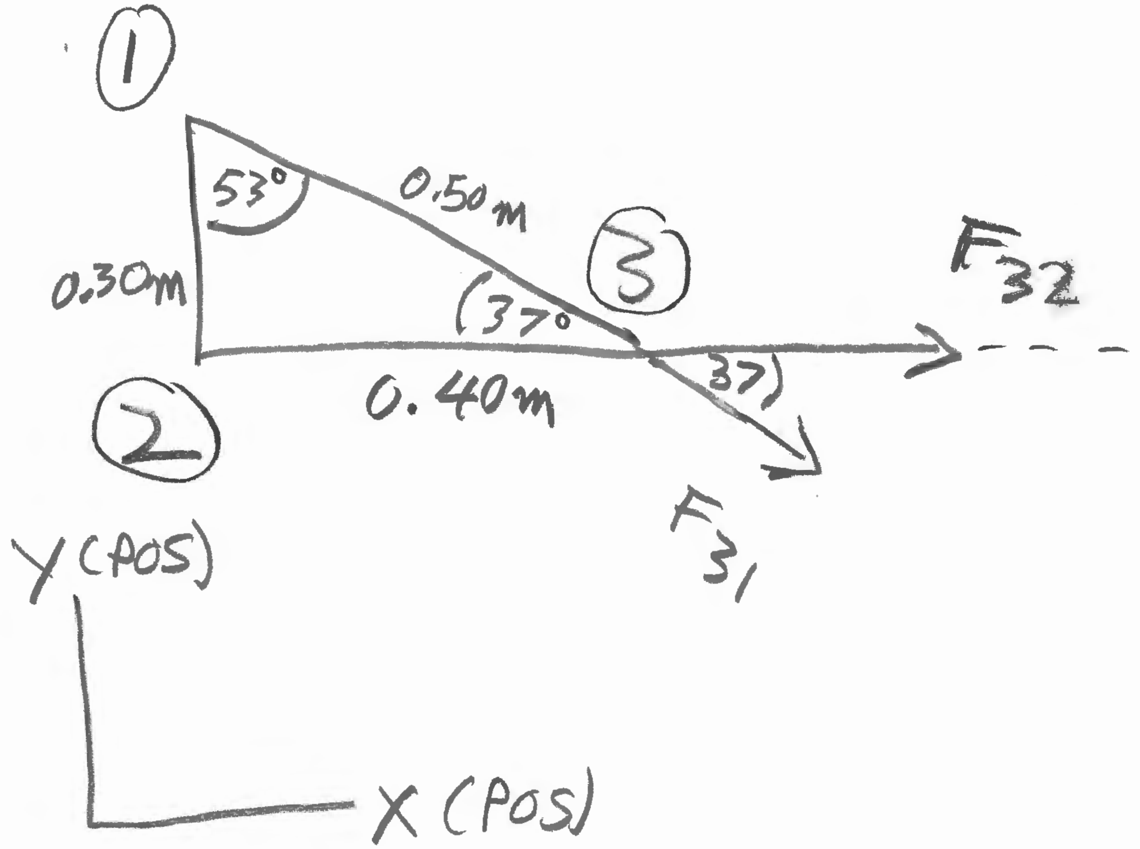
Review CH 1 (VECTORS)

PHYSICS 2A REVIEW:



$\vec{C} = \vec{A} + \vec{B}$

Parallelogram method



$$\text{ADD}\left\{\begin{array}{l} F_{31x} = F_{31} \cdot \cos 37 \\ \qquad F_{31} = \dfrac{k \cdot |q_3 \cdot q_1|}{(0.50\,m)^2} \\ F_{32x} = F_{32} \cdot \cos 0 = F_{32} \\ \qquad\qquad = \dfrac{k \cdot |q_3 \cdot q_2|}{(0.40\,m)^2} \end{array}\right.$$

ADD

$$F_{31y} = \underset{\substack{\uparrow \\ \text{QUADRant 4}}}{-}\frac{k|q_3 \cdot q_1|}{(0.50\,m)^2} \cdot \sin 37 = -F_{31} \cdot \sin 37$$

$$F_{32y} = 0 = F_{32} \cdot \sin 0$$

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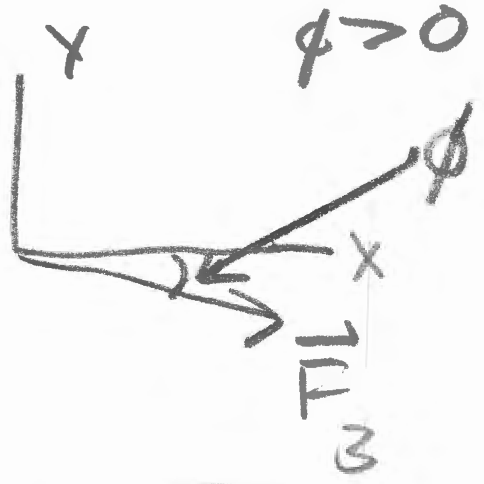

$$\tan\phi = \frac{|F_{3y}|}{|F_{3x}|}$$

Find $\tan^{-1} \frac{|F_{3y}|}{|F_{3x}|}$

$$\boxed{\phi < 37^\circ}$$

FIND $F_3 = \sqrt{F_{3x}^2 + F_{3y}^2}$

QUIZ 1 JUMPSTART:

CH 21: 82, 8, 10, 22, 76, 36, 34,
33, 35, 47, 54, 53, 55, 60,
59.

Will be posted on masteringphysics.com

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(ALL CAPS)