PHYS 242 BLOCK 1 NOTES

Sections 21.1 to 21.7

Objects may have a property called **electric charge** (usually just called **charge**) (TERM 1). The SI unit of electric charge is 1 coulomb = 1 C.

(**Electric**) **current** is the motion of (electric) charge (TERM 2). The SI unit of electric current is 1 ampere = 1 amp = 1 A. Then 1 C ≡ 1 A·s (≡ is the mathematical symbol for "is defined to equal").

Charge can be either positive (+) or negative (–).

Particle	Charge (q)	Rest Mass (m_0)	TERM
electron	$-e = -1.602 \times 10^{-19}$ C	9.109×10^{-31} kg	3
proton	$+e = +1.602 \times 10^{-19}$ C	1.673×10^{-27} kg	4
neutron	zero	1.675×10^{-27} kg	5

Neutral objects have zero *total* charge, which may result from equal magnitudes of positive and negative charges. We charge an object by adding or removing electrically-charged particles (SKILL 1).

Charges of the same sign repel one another. Charges of opposite sign attract one another (part of SKILL 4). See Figure 21.1, page 684.

The principle of **conservation of charge** is that the *total* charge (q_{total}) in an isolated system does not change (TERM 6).

The principle of **quantization of charge** is that the *total* charge of anything has only certain allowed values (TERM 7). Experimentally, $q_{\text{total}} = 0, \pm e, \pm 2e, \pm 3e, \ldots$ (except quarks have $q_{\text{total}} = \pm\frac{1}{3}e$ and $\pm\frac{2}{3}e$).

A **conductor** has many charge carriers free to carry current (TERM 8). For example, copper and aluminum have about 10^{29} free electrons/m^3.

An **insulator** has hardly any free charge carriers (TERM 9). Examples include glass and rubber.

A **semiconductor** has some free charge carriers (TERM 10). Examples include silicon, germanium, and gallium arsenide. (SKILL 2)

Coulomb's law is $\boxed{F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}}$ (for two point charges in vacuum ≈ air) (TERM 11) . In this Eq. (21.2):

F is the magnitude of the electric force (in N = newton) on *either* point charge. **Recall that the magnitudes of vectors are never negative.** (You find the direction of the force $\vec{F}$ from "Charges of the same sign repel one another. Charges of opposite sign attract one another." See Figure 21.10b, page 690.)

ε_0 is the **electric constant** (TERM 12). To four significant figures, $\varepsilon_0 = 8.854 \times 10^{-12}\ \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}$.

Therefore, $\frac{1}{4\pi\varepsilon_0} = 8.988 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2} \approx 9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$.

q_1 and q_2 are the charge values of the two point charges (in C = coulomb).

r is the separation (in m = meter) of the two point charges. Important note: r is *never* negative.

Cover up the solutions and carefully work Examples 21.1 and 21.2 on pages 692 and 693.

Recall that the total force on a body is the *vector* sum of the individual forces on it (part of SKILL 5). Cover up the solution and carefully work Example 21.3. Understand the concepts of Example 21.4.

Anywhere in the text that you find vectors described by the oxymoron "equal and opposite", realize that Roger Freedman means "equal *in magnitude* and opposite *in direction*" and add those four words.

A charged object attracts a neutral one because, since the opposite-sign *attracting* charges in the two objects are closer together and the same-sign *repelling* charges are farther apart, there is more attraction than repulsion (SKILL 3). See Figure 21.8, page 689. For the same reason, the neutral object attracts the charged one with a force that is equal in magnitude but opposite in direction.

How does an object of charge q attract or repel an object of charge q_0?
Step 1: The first object, because it has charge q, sets up an **electric field** $\vec{E}$ in the space around that object.
Step 2: The second object, because it has charge q_0, experiences an electric force $\vec{F}_0$ from that electric field (SKILL 6).

We *define* the electric field $\vec{E}$ at any point to be the electric force *per charge* $\frac{\vec{F}_0}{q_0}$ on a point test charge q_0 placed at that point. Therefore, $\vec{E}$ is in $\frac{\text{N}}{\text{C}}$ (TERM 13) . (See Figure 21.15, page 695.)

Thus the *vector* equations are $\boxed{\vec{E} \equiv \frac{\vec{F}_0}{q_0}}$ (21.3) and $\boxed{\vec{F}_0 = q_0\vec{E}}$ (21.4) , where $\vec{E}$ is an *external* electric field. (That is, $\vec{E}$ is *not* the electric field of q_0 itself.)

These vector equations tell us that $\vec{E}$ and $\vec{F}_0$ are in the *same* direction if q_0 is positive (+), but $\vec{E}$ and $\vec{F}_0$ are in *opposite* directions if q_0 is negative (–) (part of SKILL 4). (See Figure 21.16, page 696.)

To find the magnitude E of the electric field of a point charge of absolute charge value $|q|$, we follow the steps on pages 696 and 697 and arrive at Eq. (21.6), $\boxed{E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}}$ (for a point charge in vacuum ≈ air) .

If the charge q is positive (+), the electric field $\vec{E}$ it sets up is away from it (see Figures 21.17b and 21.18a), but if the charge q is negative (–), the electric field $\vec{E}$ it sets up is toward it (see Figures 21.17c and 21.18b). (part of SKILL 4) Cover up the solution and carefully work Example 21.5. In Example 21.7, understand why the force on the electron is toward the bottom of the page when the external electric field is toward the top of the page.

The total electric field at any point is the *vector* sum of the individual electric fields at that point. (part of SKILL 5) Cover up the solution and carefully work Example 21.8, skipping the EVALUATE part.

For a *continuous* distribution of charge:

1. Find $d\vec{E}$ for a general dQ using $dE = \frac{1}{4\pi\varepsilon_0}\frac{|dQ|}{r^2}$.
2. Then perform a *vector* integral of that $d\vec{E}$ expression to find $\vec{E}$ (SKILL 7) .

Electric field lines (TERM 14):

1. They are used to visualize the electric field. (See many figures in this and following chapters.)
2. $\vec{E}$ is tangent to an electric field line at any point. See Figures 21.27 and 21.28.
3. E is larger where those lines are closer together (and smaller where they are farther apart). See Figure 21.28.
4. An electric field line can be said to start on a positive charge and end on a negative charge. See Figure 21.28b.

Considering property 3. above: if you look at the center of Figure 21.28b, can you see the slight error made by the artist in the positions of the red field lines just above and just below the straight center line? And can you then see the worse error in the smaller similar figure near the bottom of page 711?

An **electric dipole** is a charge arrangement containing two equal-magnitude, opposite-sign point charges that have charge values q and $-q$, and are separated by a distance r (in m) (TERM 15). By definition, $\boxed{p \equiv |q|r}$.
(I replace q and d in Eq. (21.14) with $|q|$ and r for notational consistency with Coulomb's law.)

p is the magnitude of the **electric dipole moment** vector $\vec{p}$ (in C·m) (TERM 16) .

$|q|$ is the absolute charge value of either one of the two point charges (in C).

The direction of $\vec{p}$ is *from* the negative point charge *to* the positive point charge (SKILL 8). See Figures 21.30a, 21.31 (replacing d with r), 21.32 and 21.33.

When an electric dipole is placed in a uniform external electric field $\vec{E}$, it experiences a net torque of $\vec{\tau} = \vec{r} \times \vec{F} = \vec{r} \times |q|\vec{E} = |q|\vec{r} \times \vec{E} = \vec{p} \times \vec{E}$. Thus vector Equation (21.16) is $\boxed{\vec{\tau} = \vec{p} \times \vec{E}}$. (See pages 22 and following for a vector (cross) product review.) The mathematical evaluation of Eq. (21.16) gives Eq. (21.15) (which is *not* truly a separate equation) for the magnitude of the torque, $\boxed{\tau = pE \sin \phi}$.

ϕ (phi) is the angle between the directions of the two vectors $\vec{p}$ and $\vec{E}$; $180^\circ \geq \phi \geq 0$.

$\vec{\tau}$ (tau) is the torque (in N·m). $\vec{\tau}$ is a vector perpendicular to *both* $\vec{p}$ and $\vec{E}$ in a right-hand sense. (See SKILLS 9 and 10.) In Figure 21.31 $\vec{\tau}$ is into the page, while in Figure 21.32 $\vec{\tau}$ is out of the page.

Please practice the vector product right-hand rule using the videos at phys242.ncat.edu.

The derivation on page 708 shows that $\boxed{U = -pE \cos \phi = -\vec{p} \cdot \vec{E}}$, including Eq. (21.17), which is the mathematical evaluation of Eq. (21.18). (See pages 19 and following for a scalar (dot) product review.)

This U is the electric potential energy (in J = joule). Energy is a scalar quantity, so U has no direction.
Cover up the solutions and carefully work Example 21.13 (we use $p = |q|r$ rather than $p = qd$).

Understand Example 21.14's concepts, especially that the electric fields discussed are not *external* electric fields acting on the electric dipole (such as the $\vec{E}$ in the torque and electric potential energy equations above).