LECTURE 3
Ch. 21.3,7

PHY 122. ELECTRIC DIPOLE

WORKSHOPS START TODAY!

HOMEWORK DUE ON SATURDAY 5 pm

→ PUT IN YOUR TA LOCKER IN FRONT OF B&L 106.

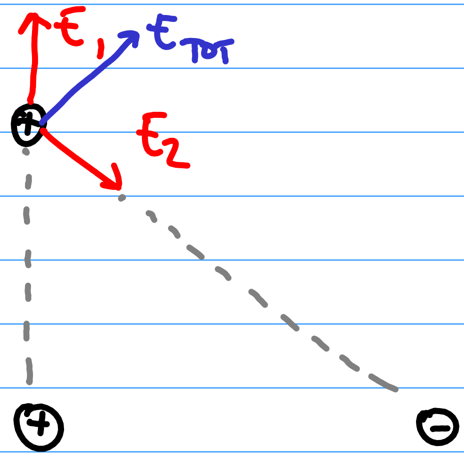
WORKSHOP, HOMEWORK, TA INFO ARE ALL UPDATED IN BLACKBOARD.

RECAP. ELECTRIC FIELD.

$$\bar{E} = \frac{\bar{F}}{q} = k\frac{Q}{r^2}$$

- A USEFUL ABSTRACTION
- SOURCE OF CHARGES Q CREATES THE FIELD
- MEASURE THE FIELD WITH A TEST CHARGE q.

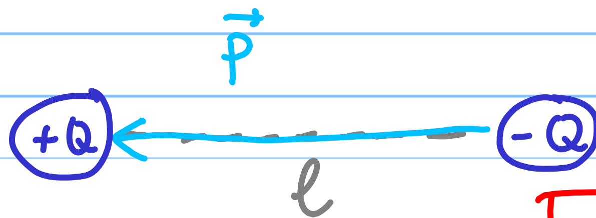
SUPERPOSITION OF FIELD:

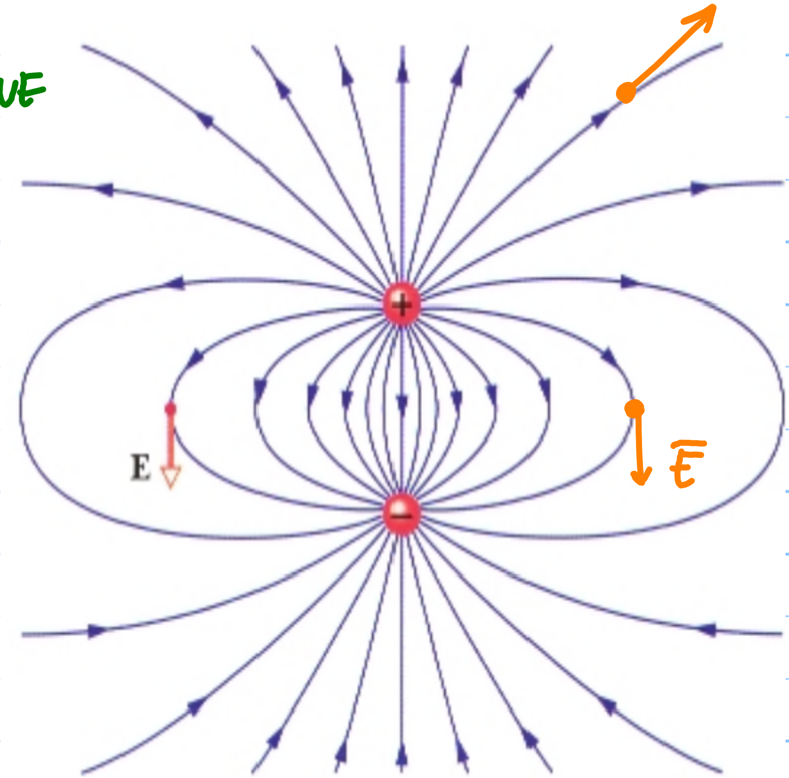


$$\bar{E}_{TOT} = \bar{E}_1 + \bar{E}_2 + \ldots$$

ELECTRIC DIPOLE

TWO OPPOSITE CHARGES OF EQUAL VALUE Q SEPARATED BY A DISTANCE ℓ

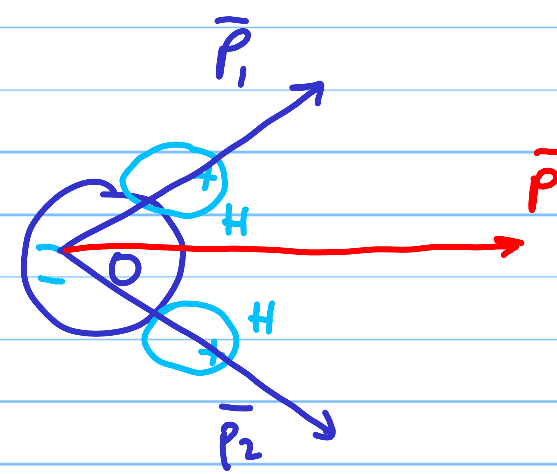




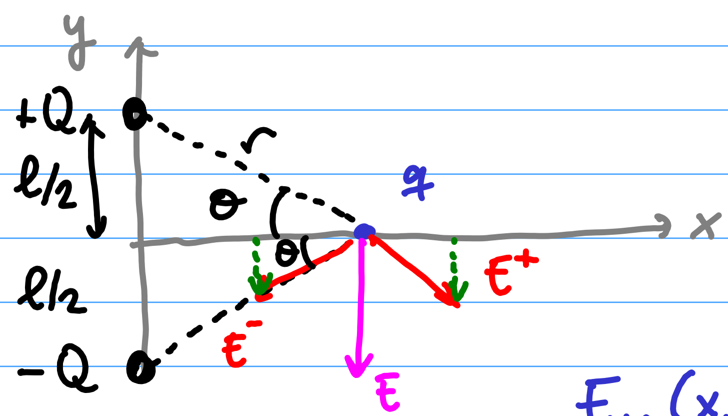
DIPOLE MOMENT: $\boxed{\vec{p} = Q\vec{\ell}}$

A VECTOR DIRECTED FROM NEGATIVE TO THE POSITIVE CHARGE, WITH MAGNITUDE $Q\ell$.

EXAMPLE: WATER MOLECULE H_2O:



FIELD CREATED BY A DIPOLE



FOR A POINT ALONG x-axis $(x,0)$

$E_x(x,0)=0$ $\quad$ $E_y(x,0)$?

E_x^- and E_x^+ cancel each other

$$E_y(x,0) = E_y^- + E_y^+ = -k\frac{Q}{r^2}\sin\theta - k\frac{Q}{r^2}\sin\theta =$$

$$E_y(x,0) = -2\frac{kQ}{r^2}\sin\theta$$

From trigonometry: $r\sin\theta = \frac{\ell}{2} \rightarrow \sin\theta = \frac{\ell}{2r}$. So:

$$\boxed{E_y(x,0) = -\cancel{2}k\frac{Q}{r^2}\cdot\frac{\ell}{\cancel{2}r} = -k\frac{Q\ell}{r^3} = \boxed{-k\frac{p}{r^3}}}$$

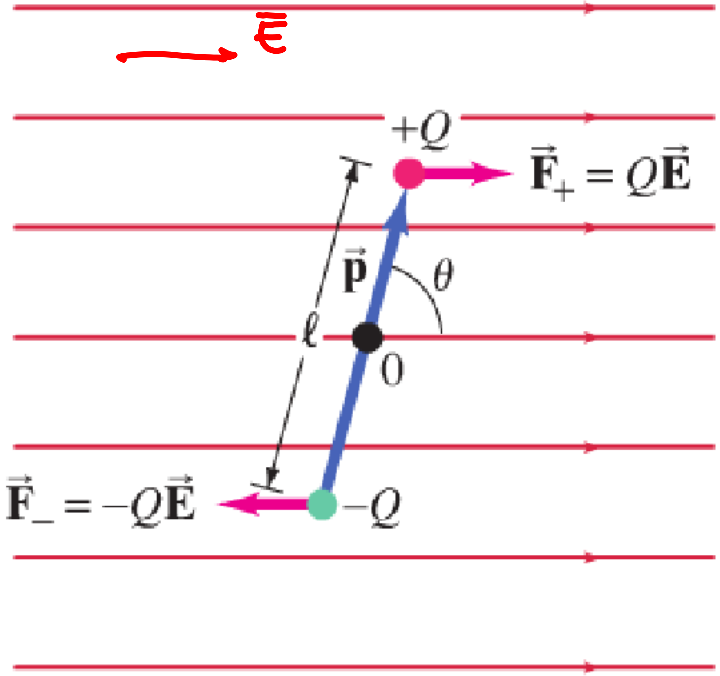
spherical coord.

And also: $r^2 = x^2 + y^2 = x^2 + \left(\frac{\ell}{2}\right)^2$

$$\boxed{E_y(x,0) = -k\frac{p}{\left(x^2+\left(\frac{\ell}{2}\right)^2\right)^{3/2}}}$$

Cartesian coord.

ELECTRIC DIPOLE IN A UNIFORM EXTERNAL FIELD



NET FORCE: $\bar{F} = \bar{F}_+ + \bar{F}_- = 0$

HOWEVER, THERE IS A TORQUE

$$\vec{\tau} = \bar{r} \times \bar{F} \quad ; |\vec{\tau}| = rF\sin\theta$$

NET TORQUE: $\bar{\tau} = \bar{\tau}_+ + \bar{\tau}_-$ (* SEE NEXT PAGE)

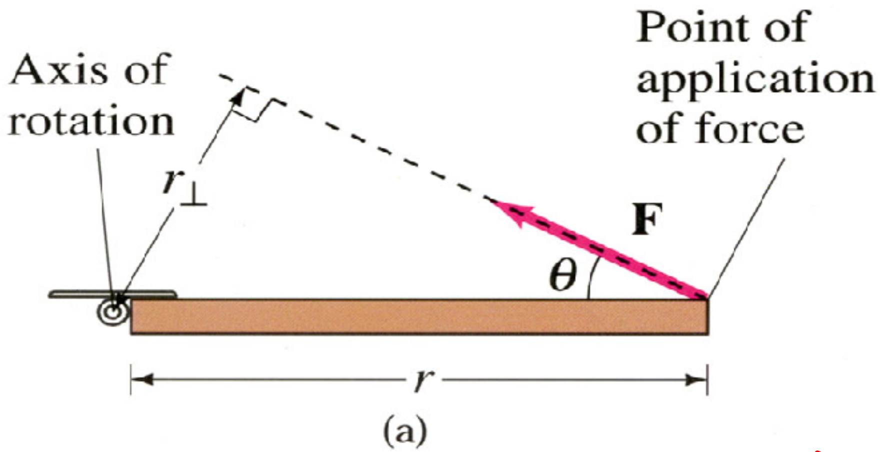
$$\tau = \frac{\ell}{2} F_+ \sin\theta + \frac{\ell}{2} F_- \sin\theta = \ell F \sin\theta$$

$F = F_\pm = QE$ (Q in this case is the test charge)

$$\tau = E \overbrace{Q\ell}^{p} \sin\theta = E\,p\,\sin\theta \rightarrow \boxed{\vec{\tau} = \vec{p} \times \vec{E}}$$

* WE ADD τ_+ AND τ_- BECAUSE THEY BOTH WANT TO ROTATE THE DIPOLE CLOCKWISE.

RECAP ON TORQUES:



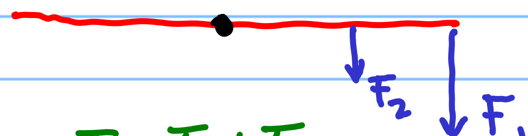
$$\bar{\tau} = \bar{r} \times \bar{F}$$

$$\tau = r F_\perp = r F \sin\theta$$

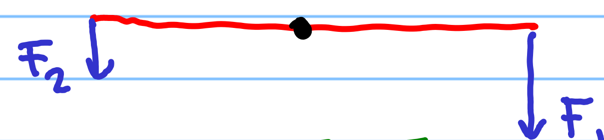
RIGHT HAND RULE

HOW TO ADD TORQUES?

IN PROBLEMS: YOU SHOULD SPECIFY WHAT YOU TAKE TO BE THE POSITIVE TORQUE DIRECTION.



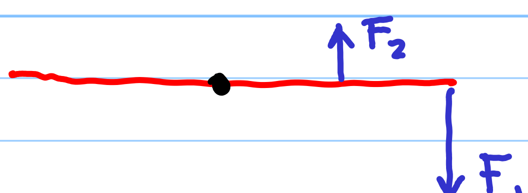
$\tau = \tau_1 + \tau_2$



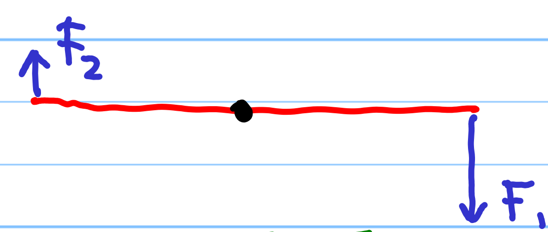
$\tau = \tau_1 - \tau_2$

ONLY THE RELATIVE SIGN MATTERS!

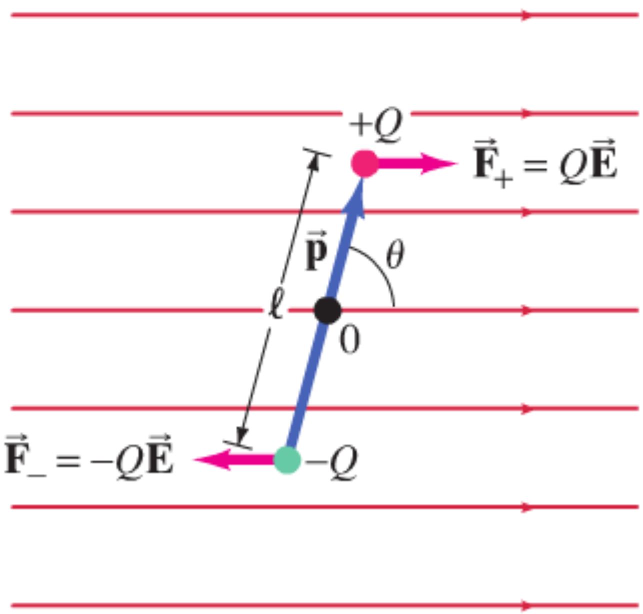
IF EACH FORCE INDIVIDUALLY CONTRIBUTES TO SAME DIRECTION OF ROTATION: ADD.
IF THEY ARE DIFFERENT: SUBTRACT



$\tau = \tau_1 - \tau_2$



$\tau = \tau_1 + \tau_2$



$$\bar{\tau} = \bar{p} \times \bar{E} = pE\sin\theta$$

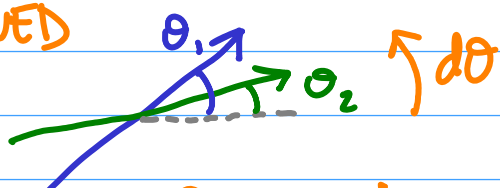
THE FIELD TRIES TO ALIGN THE DIPOLE IN THE DIRECTION OF THE FIELD.

WORK DONE BY THE FIELD:

$$W = \int_{\theta_1}^{\theta_2} \tau \, d\theta = -Ep\int_{\theta_1}^{\theta_2} \sin\theta \, d\theta =$$

$$= Ep \cos\theta \Big]_{\theta_1}^{\theta_2} = Ep(\cos\theta_2 - \cos\theta_1)$$

WE NEED TO ADD A − IN THE INTEGRAL BECAUSE $d\theta$ IS DEFINED



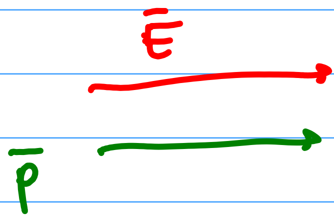
BUT $\theta_1 > \theta_2$ IN THIS CASE.

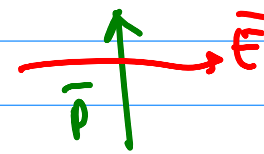
POSITIVE WORK BY THE FIELD DECREASES THE POTENTIAL ENERGY

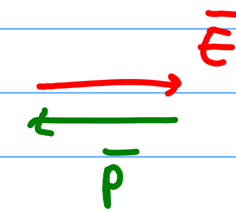
$$\Delta U = -W$$

CHOOSE $U = 0$ WHEN $\bar{p} \perp$ TO THE FIELD: $\theta_1 = 90° \rightarrow \cos\theta_1 = 0$

$$U = -W = -pE\cos\theta = -\bar{p}\cdot\bar{E} \Rightarrow \boxed{U = -\vec{p}\cdot\vec{E}}$$







$\theta = 0 \quad U = -pE$ $\qquad$ $\theta = 90° \quad U = 0$ $\qquad$ $\theta = 180° \quad U = pE$

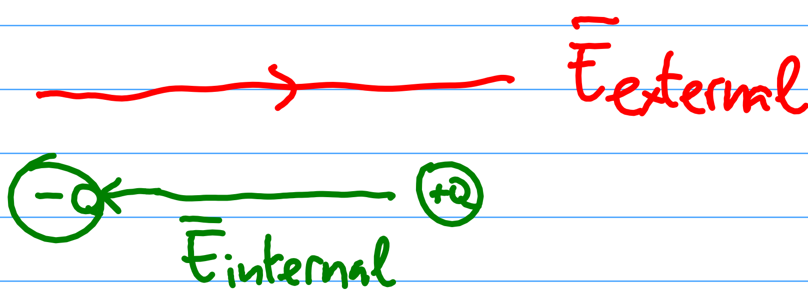
LOWEST ENERGY STATE: DIPOLE PARALLEL TO THE FIELD

DIPOLES LINE UP WITH FIELDS

INCLUDING THE FIELD OF OTHER DIPOLES

AND ALIGNED DIPOLES ARE ATTRACTED TO EACH OTHER

→ NET FIELD IS REDUCED



$$\bar{E}_{net} = \bar{E}_{external} + \bar{E}_{internal} < \bar{E}_{ext}.$$

DIPOLE: $E \propto \frac{1}{r^3}$

Dipole fields are very short range. This implies:

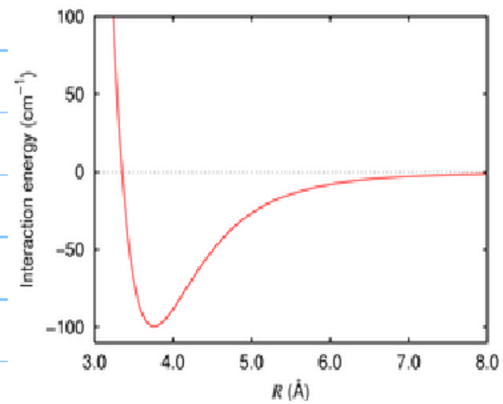
very short range for important intermolecular interactions

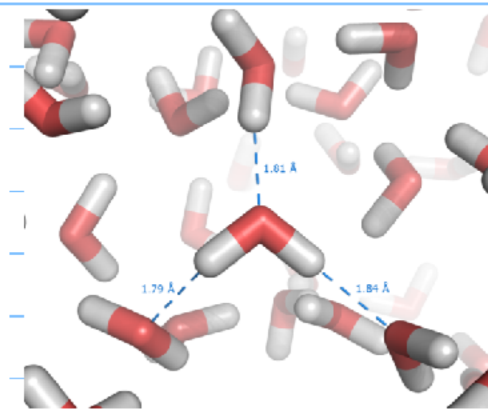
attraction between hydrogen and electronegative atoms

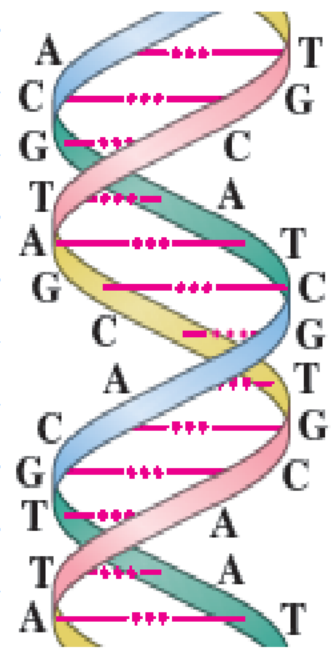
important effect in water! and in DNA!

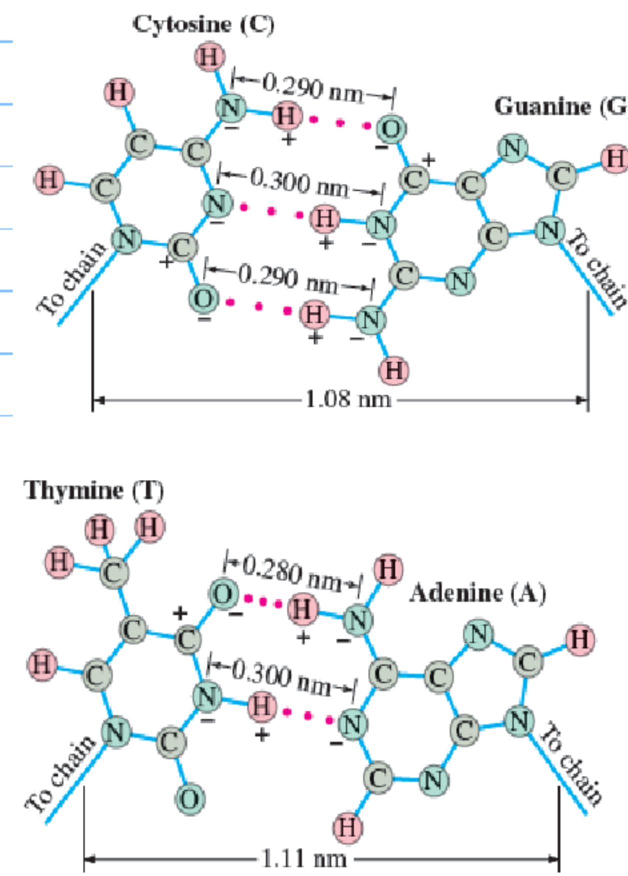
In the case of water, these weak bonds form the crystalline structure of ice

Giancoli has a nice discussion of DNA

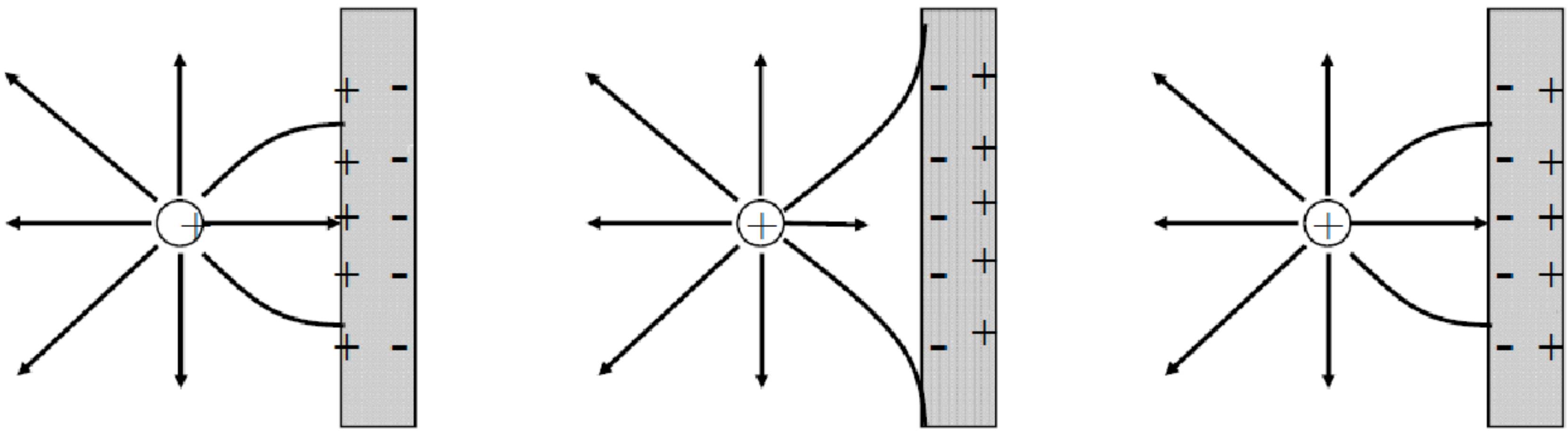




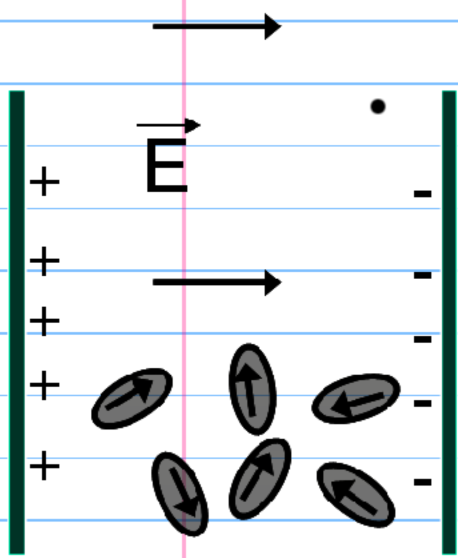




2.4 A point charge is located near a conducting plate. Choose the figure that best represents the field lines and charge configuration of the conductor

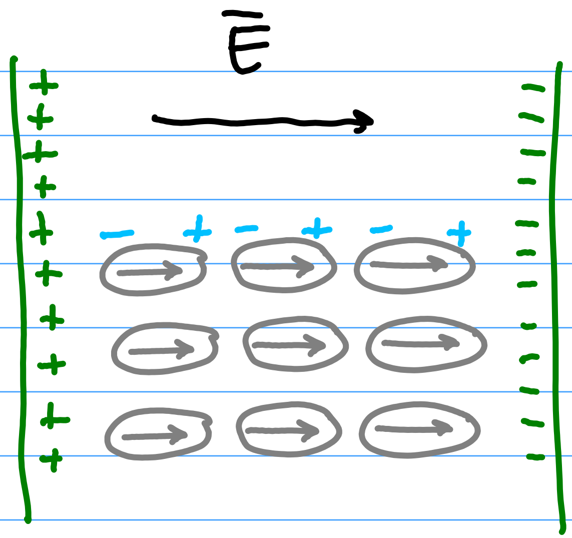


(1) (2) (3)



- 2.5 Polar molecules, like water, have small dipole moments. A region of electric field is created by giving equal and opposite charges to two parallel conducting plates. If this region is filled with pure water (an excellent insulator), does the electric field…

a) Increase b) Decrease c) Stay the same



THE POSITIVE CHARGE IS SHIELDED BY THE NEGATIVE CHARGES OF THE ALIGNED DIPOLES (AND VICEVERSA)

$\downarrow$

$\bar{E}$ IS REDUCED