Phys102 Lecture 4 &5

Electric Dipoles

Key Points

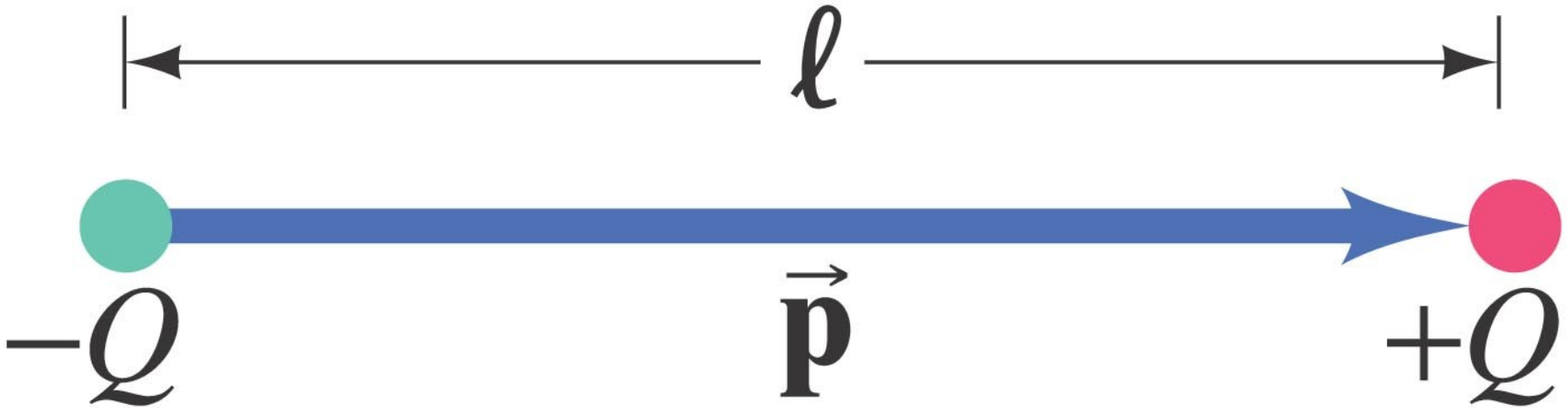
- Electric dipole
- Applications in life sciences

References

6th Ed: 16-11,+.

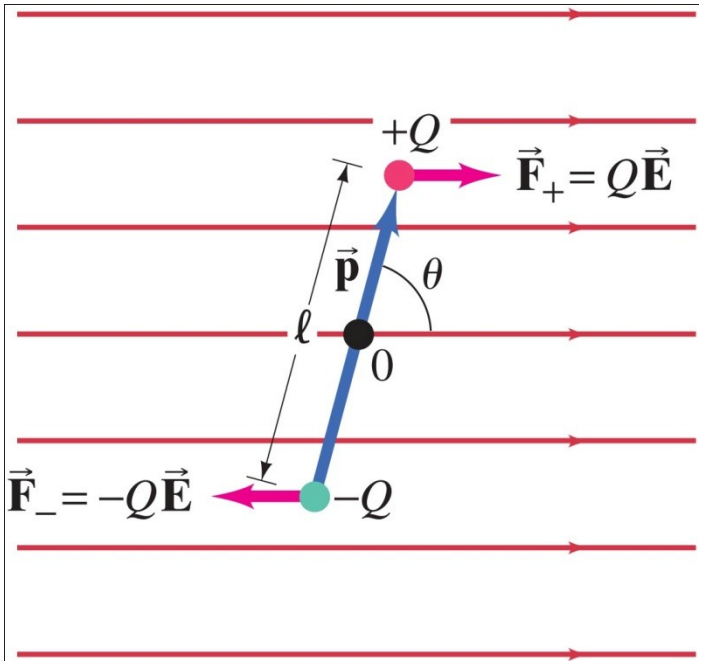
Electric Dipoles

An electric dipole consists of two charges Q, equal in magnitude and opposite in sign, separated by a distance ℓ. The dipole moment, $\vec{p} = Q\ell$, points from the negative to the positive charge.



An electric dipole in a uniform electric field will experience no net force, but it will, in general, experience a torque:

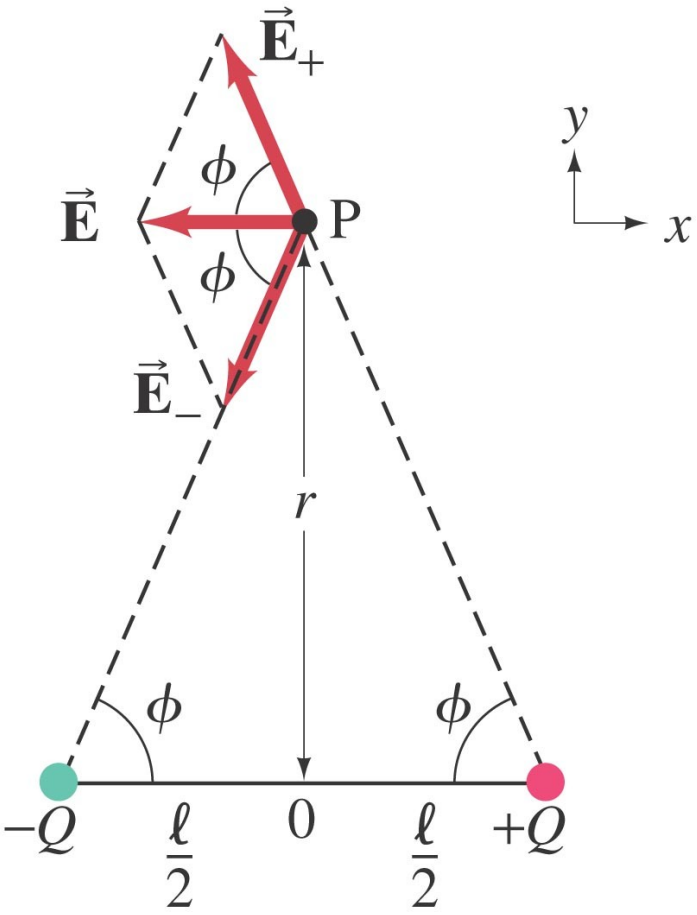
$$\tau = QE\frac{\ell}{2}\sin\theta + QE\frac{\ell}{2}\sin\theta = pE\sin\theta.$$



The electric field created by a dipole is the sum of the fields created by the two charges; far from the dipole, the field shows a $1/r^3$ dependence:

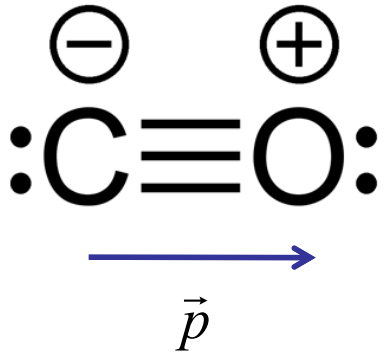
$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{\left(r^2 + \ell^2/4\right)^{\frac{3}{2}}}. \qquad \left[\begin{array}{c}\text{on perpendicular bisector}\\ \text{of dipole}\end{array}\right]$$

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{r^3}. \qquad \left[\begin{array}{c}\text{on perpendicular bisector}\\ \text{of dipole; } r \gg \ell\end{array}\right]$$



Electric dipole moment of a CO molecule

In a carbon monoxide molecule, the electron density near the carbon atom is greater than that near the oxygen, which result in a dipole moment.



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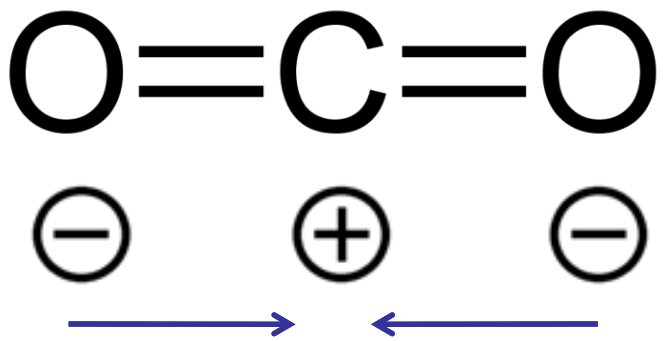
Does a carbon dioxide molecule carry an electric dipole moment?



$$\vec{p} = \vec{p}_1 + \vec{p}_2 = 0$$

A) No, because the molecule is electrically neutral.
B) Yes, because of the uneven distribution of electron density.
C) No, because the molecule is symmetrical and the net dipole moment is zero.
D) Can't tell from the structure of the molecule.

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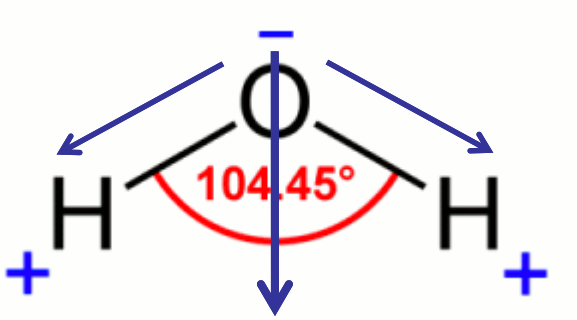
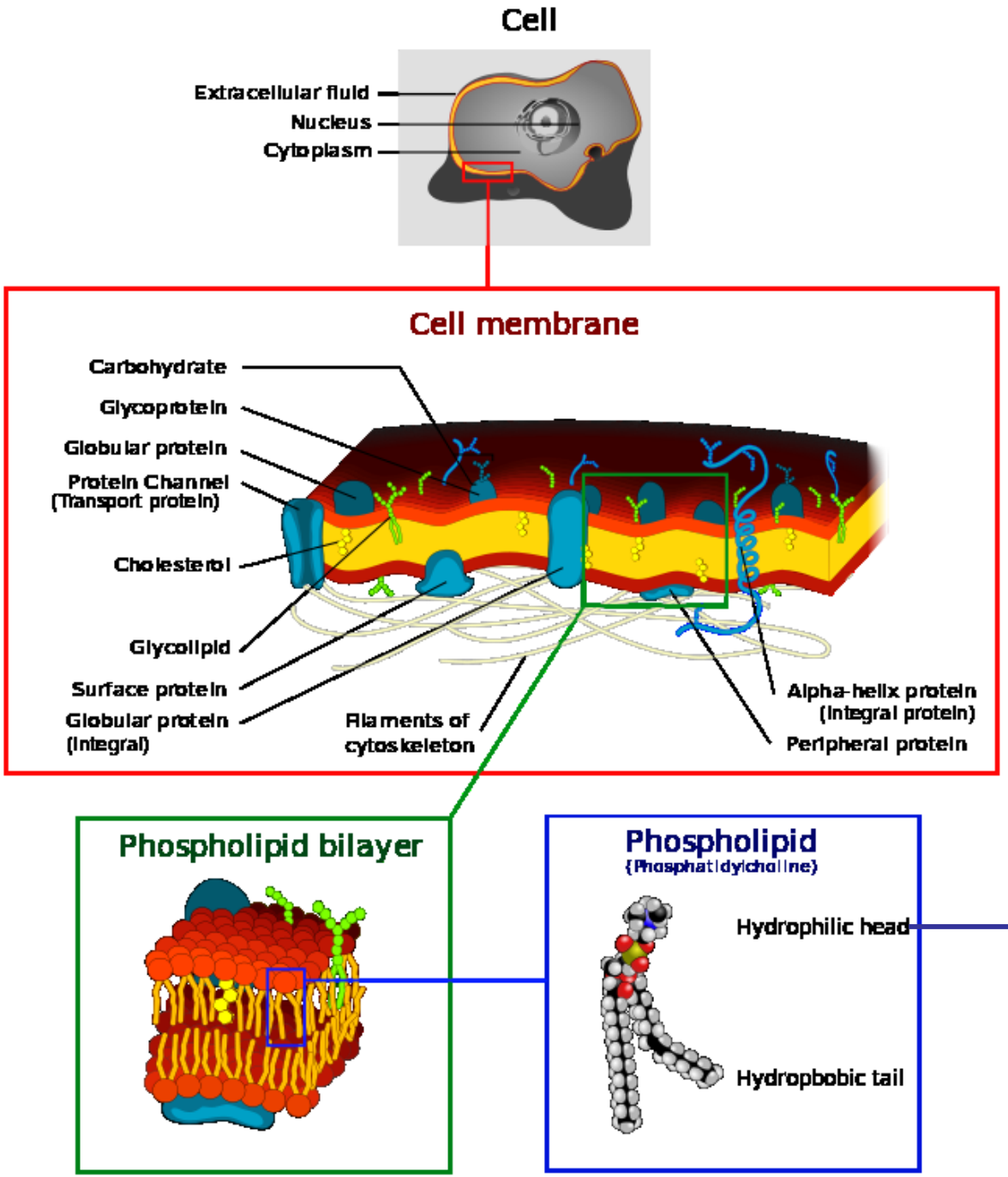
Does a water molecule carry an electric dipole moment?



$$\vec{p} = \vec{p}_1 + \vec{p}_2 \neq 0$$

A) No, because the molecule is electrically neutral.
B) No, because the molecule is symmetrical and the net dipole moment is zero.
C) Yes, because of the uneven distribution of electron density and the asymmetrical structure.
D) Can't tell from the structure of the molecule.



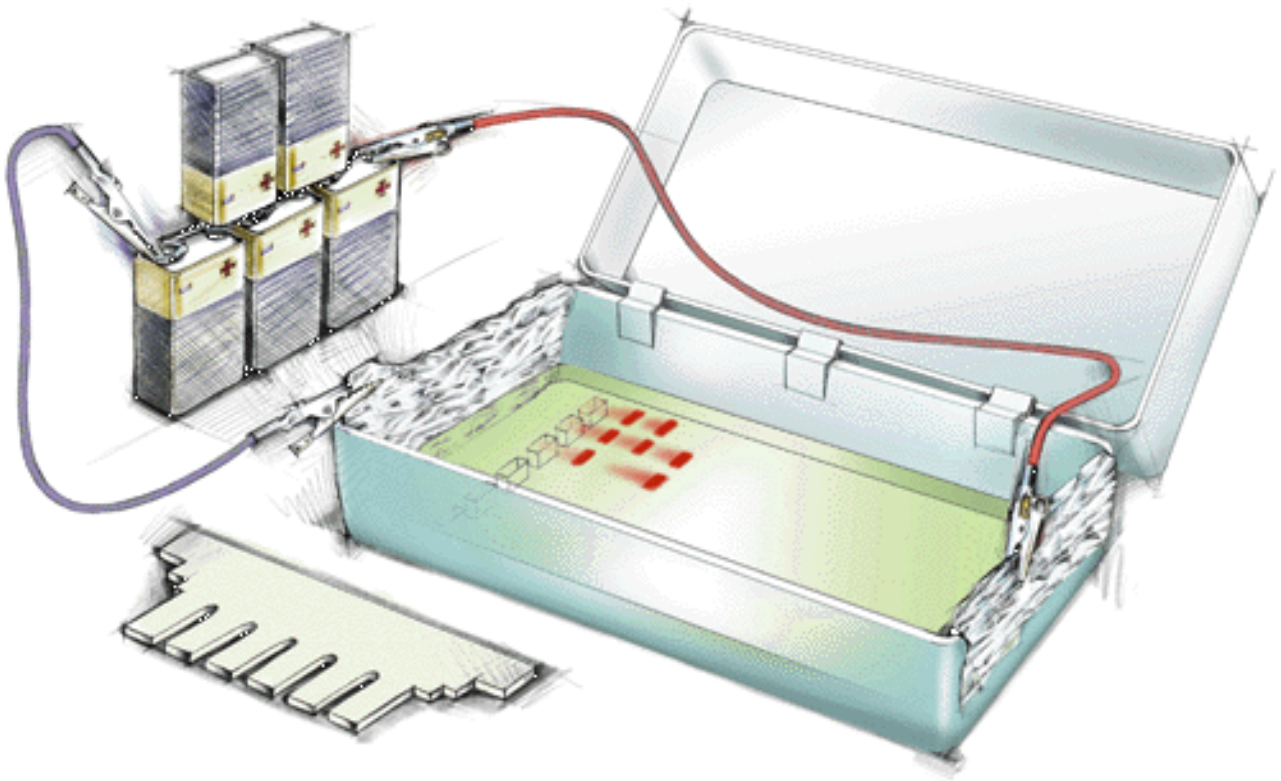
Polar
(carries a dipole)

Example: Dipole in a field.

The dipole moment of a water molecule is 6.1×10^{-30} C·m. A water molecule is placed in a uniform electric field with magnitude 2.0×10^{5} N/C. (a) What is the magnitude of the maximum torque that the field can exert on the molecule? (b) What is the potential energy when the torque is at its maximum? (c) In what position will the potential energy take on its greatest value? Why is this different than the position where the torque is maximum?

Electrophoresis

Electrophoresis is the migration of charged particles, usually macromolecules, such as DNA and proteins, under the influence of an electric field. It is an analytical technique widely used to separate different macromolecules, typically by size or charge.



Electrophoresis

If a macromolecule with a net charge q is in a uniform external electric field, the net force on the molecule given by

$$\vec{F} = q\vec{E}.$$

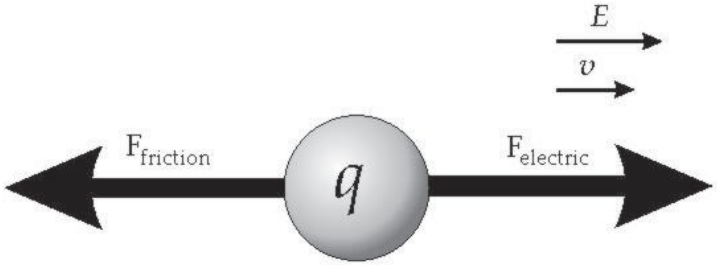
When the molecule is moving in a viscous medium, such as water or gel, it experiences a drag force proportional to the speed of the molecule.

$$\vec{F}_{drag} = -c\vec{v}$$

In general, the drag force will grow rapidly and balance the electric force, and the macromolecule will reach a constant velocity (similar to the terminal velocity of a falling object in air).

$$q\vec{E} - c\vec{v} = 0$$

$$\vec{v} = \frac{q\vec{E}}{c}$$



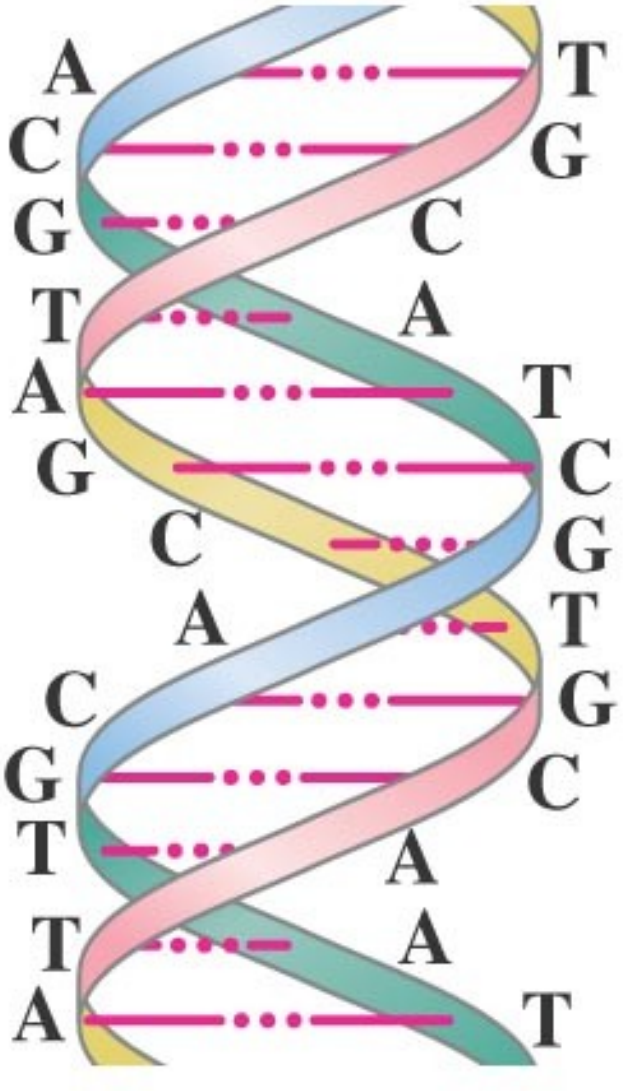
An intrinsic property of the macromolecule called the electrophoretic mobility is defined as

$$U = \frac{v}{E} = \frac{q}{c}.$$

Electric Forces in Molecular Biology; DNA

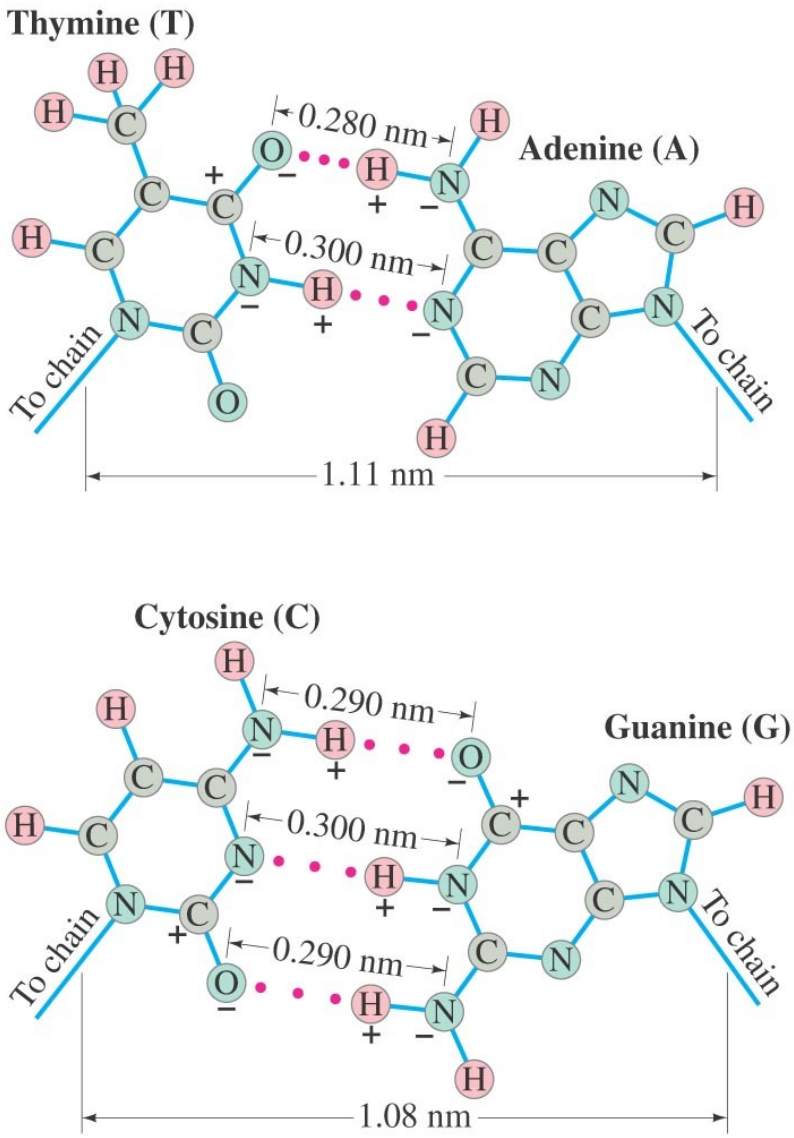
Molecular biology is the study of the structure and functioning of the living cell at the molecular level.

The DNA molecule is a double helix:



Electric Forces in Molecular Biology; DNA

The A-T and G-C nucleotide bases attract each other through electrostatic forces.



Electric Forces in Molecular Biology; DNA

Replication: DNA is in a "soup" of A, C, G, and T in the cell. During random collisions, A and T will be attracted to each other, as will G and C; other combinations will not.