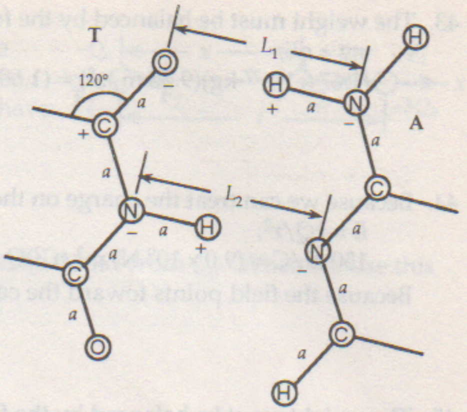


40. (*a*) To estimate the force between a thymine and an adenine, we assume that only the atoms with an indicated charge make a contribution. Because all charges are fractions of the electronic charge, we let

$Q_H = Q_N = f_1 e$, and $Q_O = Q_C = f_2 e$.

A convenient numerical factor will be

$ke^2/(10^{-10}\ \text{m}/\text{Å})^2$

$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2/(10^{-10}\ \text{m}/\text{Å})^2$

$= 2.30\times10^{-8}\ \text{N}\cdot\text{Å}^2$.

For the first contribution we find the force for the bond of the oxygen on the thymine with the H-N pair on the adenine. From Newton's third law, we know that the force on one must equal the force on the other. We find the attractive force on the oxygen:

$F_O = kQ_O\{[Q_H/(L_1 - a)^2] - (Q_N/L_1^2)\}$

$= ke^2 f_2 f_1\{[1/(L_1 - a)^2] - (1/L_1^2)\}$

$= (2.30\times10^{-8}\ \text{N}\cdot\text{Å}^2)(0.4)(0.2)\{[1/(2.80\ \text{Å} - 1.00\ \text{Å})^2] - [1/(2.80\ \text{Å})^2]\} = 3.33\times10^{-10}\ \text{N}$.

For the force for the lower bond of the H-N pair on the thymine with the nitrogen on the adenine, we find the attractive force on the nitrogen:

$F_N = kQ_N\{[Q_H/(L_2 - a)^2] - (Q_N/L_2^2)\} = ke^2 f_1 f_1\{[1/(L_2 - a)^2] - (1/L_2^2)\}$

$= (2.30\times10^{-8}\ \text{N}\cdot\text{Å}^2)(0.2)(0.2)\{[1/(3.00\ \text{Å} - 1.00\ \text{Å})^2] - [1/(3.00\ \text{Å})^2]\} = 1.28\times10^{-10}\ \text{N}$.

There will be a repulsive force between the oxygen of the first bond and the nitrogen of the second bond. To find the separation of the two, we note that the distance between the two nitrogens of the adenine, which is approximately perpendicular to $L_1$, is $2a \cos 30° = 1.73a$. We find the magnitude of this force from

$F_{O\text{-}N} = kQ_O\{Q_N/[L_1^2 + (1.73a)^2]\} = ke^2 f_2 f_1\{1/[L_1^2 + (1.73a)^2]\}$

$= (2.30\times10^{-8}\ \text{N}\cdot\text{Å}^2)(0.4)(0.2)\{1/[(2.80\ \text{Å})^2 + (1.73\ \text{Å})^2]\} = 1.7\times10^{-10}\ \text{N}$.

We find the angle that this force makes with the line of the other bonds from

$\tan\theta = 1.73a/L_1 = 1.73\ \text{Å}/2.89\ \text{Å} = 0.62$, or $\theta = 32°$

Thus the component that contributes to the bond is $(1.7\times10^{-10}\ \text{N})\cos 32° = 1.4\times10^{-10}\ \text{N}$.

The other contribution will be from the carbon atom on the thymine. Because the distance is slightly greater and there will be attraction to the nitrogens and repulsion from the hydrogen, we neglect this contribution.

Thus the estimated net bond is $3.33\times10^{-10}\ \text{N} + 1.28\times10^{-10}\ \text{N} - 1.4\times10^{-10}\ \text{N}$ $\boxed{\approx 3\times10^{-10}\ \text{N}.}$

(*b*) To estimate the net force between a cytosine and a guanine, we note that there are two oxygen bonds, one nitrogen bond, and one repulsive O-N force. We neglect the other forces because they involve cancellation from the involvement of both hydrogen and nitrogen. If we ignore the small change in distances, we have

$2(3.33\times10^{-10}\ \text{N}) + 1.28\times10^{-10}\ \text{N} - 1.4\times10^{-10}\ \text{N}$ $\boxed{\approx 7\times10^{-10}\ \text{N}.}$

(*c*) The total force for the DNA molecule is

$(3\times10^{-10}\ \text{N} + 7\times10^{-10}\ \text{N})(10^5\ \text{pairs})$ $\boxed{\approx 10^{-4}\ \text{N}.}$

41. When we equate the two forces, we have

$mg = ke^2/r^2$;

$(9.11\times10^{-31}\ \text{kg})(9.80\ \text{m/s}^2) = (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2/r^2$, which gives $r =$ $\boxed{5.08\ \text{m}.}$

42. Because a copper atom has 29 electrons, we find the number of electrons in the penny from

$N = [(3.0\ \text{g})/(63.5\ \text{g/mol})](6.02\times10^{23}\ \text{atoms/mol})(29\ \text{electrons/atom}) = 8.24\times10^{23}$ electrons.

We find the fractional loss from

$\Delta q/q = (42\times10^{-6}\ \text{C})/(8.24\times10^{23}\ \text{electrons})(1.6\times10^{-19}\ \text{C/electron}) =$ $\boxed{3.2\times10^{-10}.}$