b) The Newton’s third law force pairs are:

1. The electrical force of each sphere on the other;
2. The normal force of the puck on the sphere and the normal force of the sphere on the puck; and
3. The static force of friction of the puck on the sphere and the sphere on the puck.

c) Choose the puck and sphere on the left and take \( \hat{i} \) horizontally to the right. Applying Newton’s second law to the sphere, we have

\[
F_{x, \text{total}} = m_{\text{sphere}} a_x
\]

\[
\Rightarrow F_{\text{electrical}} - f_s = m_{\text{sphere}} a_x.
\]

For the puck on which this sphere rests,

\[
f_s = m_{\text{puck}} a_x.
\]

16.16

a) Let the individual (positive) charges be \( q_1 \) and \( q_2 \). We are told that

\[
q_1 + q_2 = Q.
\]

The magnitude of the force of each charge on the other is

\[
F_{\text{electric}} = \frac{1}{4 \pi \epsilon_0} \frac{q_1 q_2}{r^2}.
\]

We are told that both charges are positive, so

\[
F_{\text{electric}} = \frac{1}{4 \pi \epsilon_0} \frac{q_1 (Q - q_1)}{r^2}
\]

\[
= \frac{1}{4 \pi \epsilon_0} \frac{q_1 Q - (q_1)^2}{r^2}.
\]

To find the value of \( q_1 \) that maximizes \( F_{\text{electric}} \), first differentiate it with respect to \( q_1 \), set the result equal to zero and solve for \( q_1 \):

\[
\frac{d}{dq_1} F_{\text{electric}} = \frac{1}{4 \pi \epsilon_0} \frac{Q - 2q_1}{r^2} = 0 \text{ N/C}
\]

\[
\Rightarrow Q - 2q_1 = 0 \text{ C}
\]

\[
\Rightarrow q_1 = \frac{Q}{2} \quad \text{and} \quad q_2 = Q - q_1 = \frac{Q}{2}.
\]

Therefore, the maximum magnitude force occurs when the two charges have equal magnitudes, with each having half of the total charge. (You can verify that this value of \( q_1 \) is indeed a maximum by graphing the derivative on your calculator, or by evaluating the second derivative of \( F_{\text{electric}} \) with respect to \( q_1 \) and showing that it is less than zero at the extremum point \( q_1 = Q/2 \).)

b) The minimum force has magnitude 0 N, which occurs when \( q_1 = Q \) and \( q_2 = 0 \) C or vice versa.

16.17

a) The forces on each mass are:

1. its weight \( \vec{w} \), of magnitude \( mg \), directed down;
2. the force \( \vec{T} \) of the cord, pointing away from the mass and along the cord; and
3. The electrical force $\vec{F}_{\text{elec}}$, pointing horizontally away from the other mass. (Since the charges are like charges, this force is repulsive.)

Here is the second law force diagram for each mass, and an appropriate coordinate system.

![Force Diagram](image)

b) Consider just the mass on the left as the system. In the above coordinate system, the forces on it are:

$$\vec{w} = -mg\hat{j}, \quad \vec{T} = T\sin\theta\hat{i} + T\cos\theta\hat{j}, \quad \text{and} \quad \vec{F}_{\text{elec}} = -F_{\text{elec}}\hat{i}.$$ 

The separation of the charges is $r = 2\ell \sin\theta$, so

$$F_{\text{elec}} = \frac{1}{4\pi\varepsilon_0} \frac{|q||q|}{r^2} = \frac{1}{4\pi\varepsilon_0} \frac{q^2}{4\ell^2 \sin^2\theta}.$$ 

The mass is in static equilibrium, so the total force on it is zero. Thus, in the $x$ direction we have

$$T\sin\theta - \frac{1}{4\pi\varepsilon_0} \frac{q^2}{4\ell^2 \sin^2\theta} = 0 \text{ N}.$$ 

In the $y$ direction we have

$$-mg + T\cos\theta = 0 \text{ N} \implies T = \frac{mg}{\cos\theta}.$$ 

Now substitute this expression for $T$ into (1) and solve for $q$.

$$\frac{mg}{\cos\theta} \sin\theta - \frac{1}{4\pi\varepsilon_0} \frac{q^2}{4\ell^2 \sin^2\theta} = 0 \text{ N} \implies mg\tan\theta - \frac{1}{4\pi\varepsilon_0} \frac{q^2}{4\ell^2 \sin^2\theta} = 0 \text{ N} \implies |q| = 2\ell \sin\theta \sqrt{4\pi\varepsilon_0 mg \tan\theta}.$$ 

c) Substitute the numerical values and change the mass units from grams to kilograms:

$$|q| = 2\ell \sin\theta \sqrt{4\pi\varepsilon_0 mg \tan\theta} = 2\ell \sin\theta \sqrt{\frac{mg \tan\theta}{4\pi\varepsilon_0}}$$

$$= 2(0.500 \text{ m}) \sin 15.0^\circ \sqrt{(0.010 \text{ kg})(9.81 \text{ m/s}^2) \tan 15.0^\circ} = 4.4 \times 10^{-7} \text{ C}.$$ 

Notice that in working this and similar problems, we find it more convenient to work with the numerical value of $\frac{1}{4\pi\varepsilon_0} = 9.00 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$ than with the numerical value of $4\pi\varepsilon_0$.

d) The charge quantum number $n$ is found from

$$q = ne \implies n = \frac{q}{e} = \pm 4.4 \times 10^{-7} \text{ C} \pm 2.7 \times 10^{12}.$$