(p) **(1 pt.)** Coulomb's friction law is **exact/highly accurate/approximate/wrong**.

(q) **(1 pt.)** The range for μ_s, the coefficient of static friction, is $0 \leq \mu_s \leq 1$. **True/False**.

(r) **(1 pt.)** Electromagnetic repulsion of two protons is **much weaker/weaker/stronger/much strong** than their gravitational attraction.

(s) **(2 pts.)** The first measurement of the "universal gravitational constant" G in 1798 by Cavendish and recent (year 2000^+) experiments of G are estimated to be accurate to approximately:

Experiments in 1798	10%	1%	0.001%	10^{-7}%	infinite
Experiments in 2000^+	10%	1%	0.001%	10^{-7}%	Infinite

(t) **(2 pts.)** What **two** questions does statics answer?

- Where is it? (i.e., what is the configuration of system components).
- What are the forces on it?

(u) **(3 pts.)** What are the **two** steps in a free-body diagram?

- Identify your system.
- Identity the external **contact** and **distance** forces on the system.

(v) **(2 pts.)** What are the **two** vector equations used for **static equilibrium** of a system S?

- $\mathbf{F}^S = \mathbf{0}$
- $\mathbf{M}^{S/O} = \mathbf{0}$ where O is **any** point

(w) **(8 pts.)** **Replacement of contact forces on a baseball bat.**

The figure to the right shows a forearm and hand modeled as a single rigid body A that uses a complex set of muscles, bones, ligaments, and tendons to grip a baseball bat B in such a way that a point Q of B cannot translate relative to a point P of A and B is only free to rotate relative to A about B's long axis.

Note: Point Q is on the butt-end of the bat and is on B's symmetry axis.

Note: Point P is the point of A coincident with Q.

- Draw and label contact and distance forces on B (think three-dimensional)
- **Fully describe** your **contact** force and/or torque measures on B.
- To facilitate your analysis, introduce helpful unit vectors.

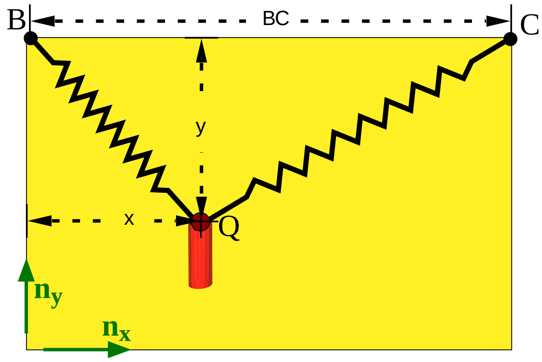
Complete description of force/torque measures (**think 3D**)	Scalar symbol
$\mathbf{b}_x$ measure of force on B from A at Q	F_x
$\mathbf{b}_y$ measure of force on B from A at Q	F_y
$\mathbf{b}_z$ measure of force on B from A at Q	F_z
$\mathbf{b}_x$ measure of torque on B from A	t_x
$\mathbf{b}_y$ measure of torque on B from A	T_y

2. **(19 pts.)** **Design and statics of hanging a picture.**

A heavy picture Q is attached to pegs B and C by two light flexible cables. Ed, the construction contractor, has cut two cables and wants to know where the picture will be with these two cables.

In addition to a horizontally right unit vector $\mathbf{n}_x$ and a vertically upward unit vector $\mathbf{n}_y$, the following table of systems facilitate this analysis.

Description	Symbol
Local gravitational constant	g
Mass of Q	m
Distance from B to C	BC
Natural length of cable $\overline{BQ}$	L_n^B
Natural length of cable $\overline{CQ}$	L_n^C
Material constant associated with springs	κ
$\mathbf{n}_x$ measure of the position vector of Q from B	x
Vertical distance from B to Q	y



(a) **(3 pts.)** Find the distance between B and Q and the distance between C and Q.
Result:

$$d_B = \sqrt{x^2 + y^2} \qquad d_C = \sqrt{(BC - x)^2 + y^2}$$

(b) **(8 pts.)** Express $\mathbf{F}^{Q/B}$ and $\mathbf{F}^{Q/C}$, (the contact forces on Q from the springs connecting Q to B and Q to C) and $\mathbf{F}^{Q/gravity}$ (the distance force on Q from gravity) in terms of symbols in the table, d_B, d_C, the spring constant k_B of the linear spring connecting Q to B, the spring constant k_C of the linear spring connecting Q to C, and $\mathbf{n}_x$ and $\mathbf{n}_y$.
Result:

$$\vec{\mathbf{F}}^{Q/B} = -k_B\,(1 - \tfrac{L_n^B}{d_B})\,(x\mathbf{n}_x - y\mathbf{n}_y)$$

$$\vec{\mathbf{F}}^{Q/C} = -k_C\,(1 - \tfrac{L_n^C}{d_C})\,[(x - BC)\mathbf{n}_x - y\mathbf{n}_y]$$

$$\vec{\mathbf{F}}^{Q/gravity} = -m\,g\,\mathbf{n}_y$$

(c) **(5 pts.)** Using free-body diagrams, form equations that govern **static equilibrium** of Q in N in terms of symbols in the table and κ.
Note: The spring constants k_B and k_C depend on the constant κ as $k_B = \frac{\kappa}{L_n^B}$ and $k_C = \frac{\kappa}{L_n^C}$.
Result:

$$\kappa\frac{BC-x}{L_B} + \kappa\frac{x}{\sqrt{x^2+y^2}} - \kappa\frac{x}{L_A} - \kappa\frac{e-x}{\sqrt{(BC-x)^2+y^2}} = 0$$

$$mg + \kappa\frac{y}{\sqrt{x^2+y^2}} + \kappa\frac{y}{\sqrt{(BC-x)^2+y^2}} - \kappa\frac{y}{L_A} - \kappa\frac{y}{L_B} = 0$$

(d) **(2 pts.)** With known values of symbols in the table, the equations governing the **static equilibrium** values of x and y simplify to (you do not need to show this)

$$1.6 - 0.16667\,x + \frac{x}{\sqrt{x^2+y^2}} - \frac{15-x}{\sqrt{(15-x)^2+y^2}} = 0$$

$$981 - 55051\,y + 330304\,\frac{y}{\sqrt{x^2+y^2}} + 330304\,\frac{y}{\sqrt{(15-x)^2+y^2}} = 0$$

With a pencil, paper, and a simple calculator, find numerical values for x and y that satisfy both equations. Alternately, describe how you would solve these equations.
Solve with a computer and an algorithm for nonlinear algebraic equations (e.g., Newton-Rhapson).

(e) **(1 pt.)** Sketch two or more configurations that may satisfy the previous set of equations.