16.1 ♣ Two types of forces in a *free-body diagram (FBD)* (Section 18.6).

From an engineering/FBD perspective, the two types of forces are ________ and ________.

16.2 ♣ What is 1 Newton and 1 lb_f? (Section 21.1).

1 Newton is defined as (circle all that apply)	$1 \frac{kg\,m}{s^2}$	$9.81 \frac{kg\,m}{s^2}$	$32.2 \frac{kg\,m}{s^2}$	None of these
$1\ lb_f$ is defined as or approximately equal to (circle all that apply)	$1\ kg \cdot \frac{m}{s^2}$ $9.81\ kg \cdot \frac{m}{s^2}$ $32.2\ kg \cdot \frac{m}{s^2}$	$1\ slug \cdot \frac{ft}{s^2}$ $9.81\ slug \cdot \frac{ft}{s^2}$ $32.2\ slug \cdot \frac{ft}{s^2}$	$1\ lb_m \cdot \frac{ft}{s^2}$ $9.81\ lb_m \cdot \frac{ft}{s^2}$ $32.2\ lb_m \cdot \frac{ft}{s^2}$	

Using the exact Section 21.1 NIST conversion factor for lbm to kg and the exact conversion factor 1 inch $\triangleq$ 2.54 cm, show how to calculate the conversion factor for lbf to Newton.

Result

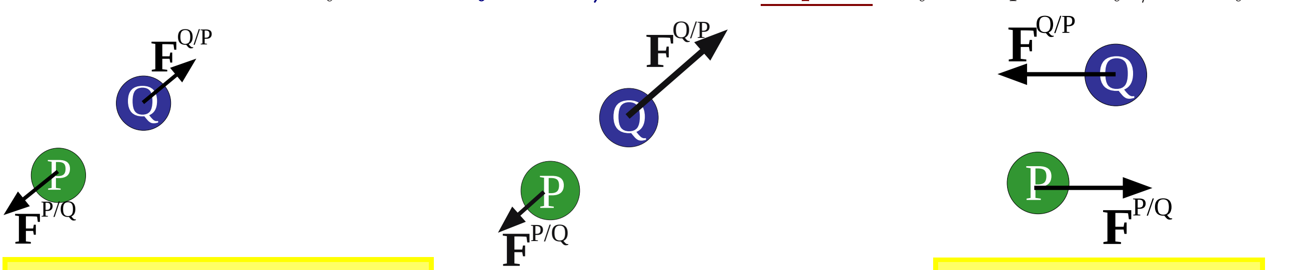
$$1\ \text{lbf} \approx \frac{\_\_\_\ \text{lbm ft}}{\text{s}^2} * \frac{\_\_\_\ \text{kg}}{\_\_\_\ \text{lbm}} * \frac{\_\_\_\ \text{inch}}{\_\_\_\ \text{ft}} * \frac{\_\_\_\ \_\_\_}{\_\_\_\ \_\_\_} * \frac{\_\_\_\ \_\_\_}{\_\_\_\ \_\_\_} * \frac{\_\_\_\ \text{N}}{\_\_\_\ \text{kg m/s}^2} \approx 4.45\ \text{N}$$

16.3 ♣ Force concepts (Section 18.3).

A force is a well-defined quantity:	**True/False**
The resultant of a set of forces is a force.	**True/False**
In the SI (metric) system, the units of force are:	________
In the SI (metric) system, the units of impulse are:	________
$\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ is violated if a non-zero forces exists without the presence of a massive object	**True/False**
$\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ is violated if mass exists without the presence of force	**True/False**

16.4 ♣ Law of action/reaction (Section 18.1).

Circle the forces that obey the ***law of action/reaction***. **Explain** why each pair obeys/disobeys.



16.5 ♣ Coulomb's friction law (Section 21.6).

The range for Coulomb's ***coefficient of static friction*** is always $0 \le \mu_s \le 1$. **True/False**.

Coulomb's friction law is **exact/accurate** (< 1% error)**/approximate/completely wrong.**

16.6 ♣ Force and mass concepts (Section 21.1).

The center of mass and center of gravity may be different points.	**True/False**
The center of gravity of a rigid body always exists.	**True/False**

16.7 ♣ Convert U.S. units of psi to SI units of Pascals and estimate stress (Section 21.1).

Use **each** conversion factors (number) below at **least once** (and others you should know) to convert units of 1 inch to $\boldsymbol{x}$ meters, 1 lbf (pound-force) to $\boldsymbol{y}$ Newtons, and 1 psi ($\frac{\text{lbf}}{\text{inch}^2}$) to $\boldsymbol{z}$ Pascals ($\frac{\text{N}}{\text{m}^2}$).
Express your results for $\boldsymbol{z}$ in terms of the intermediate conversion factors $\boldsymbol{x}$ and $\boldsymbol{y}$.

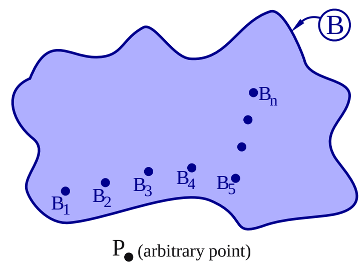
$$1 \text{ inch} \triangleq 2.54 \text{ cm} \qquad 1 \text{ kg} \approx 2.2 \text{ lbm} \qquad 1 \; g_{\text{Earth}} \approx 32.2 \; \frac{\text{ft}}{\text{s}^2}$$

Conversion	Equation (with numbers and units) for calculating result.	
1 in = $\boldsymbol{x}$ m	$\boldsymbol{x} = 1 \text{ in} \; * \; \frac{2.54 \text{ cm}}{1 \text{ in}} \; * \; \frac{1 \text{ m}}{100 \text{ cm}} \; \approx \; 0.0254$	Example of how to do units conversions
1 lbf = $\boldsymbol{y}$ N	$\boldsymbol{y} =$ ______ ≈ 4.45	
1 psi = $\boldsymbol{z}$ Pa	$\boldsymbol{z} =$ ______ ≈ 6894.757	Express $\boldsymbol{z}$ in terms of $\boldsymbol{x}$ and $\boldsymbol{y}$

Engineering skill: Estimate/approximate order-of-magnitudes for mass, force, and stress.

Mass of a laptop computer	**0.04/0.4/4/40/400**	lbm
Weight of a laptop computer	**0.04/0.4/4/40/400**	lbf
Weight of a laptop computer	**0.02/0.2/2/20/200**	Newtons
Gage pressure in a bike tire (remember pumping up a bike/car tire?)	**0.05/0.5/5/50/500**	psi
Gage pressure in a bike tire	**0.03/0.3/3/30/300**	kPa
Stress of a 200 lbf person on one flat sneaker on a wood floor	**0.05/0.5/5/50/500**	psi
Stress of a 120 lbf person on one stiletto heel on a wood floor	**0.03/0.3/3/30/300**	psi

16.8 ♣ Forces on an aluminum body (Sections 18.4, 18.2, and 19.4).



Consider 6.022×10^{23} molecules of aluminum (≈ 27 grams) which define a body B. The quantities under investigation (and related moments) are:

- $\vec{\mathbf{F}}^{B}$ the resultant of all forces on B
- $\vec{\mathbf{F}}^{B}_{\text{internal}}$ the resultant of all internal forces in B
- $\vec{\mathbf{F}}^{B}_{\text{external}}$ the resultant of all external forces on B
- $\vec{\mathbf{F}}^{B_1/B_2}$ the force on molecule B_1 from molecule B_2

Condition	Static equilibrium?	Circle the following statements that are always true.
B is rigid	Yes	$\vec{\mathbf{F}}^{B} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$ $\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$ $\vec{\mathbf{M}}^{B/P} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$ $\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$
B is flexible (a thin ruler)	Yes	$\vec{\mathbf{F}}^{B} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$ $\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$ $\vec{\mathbf{M}}^{B/P} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$ $\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$
B is rigid	No	$\vec{\mathbf{F}}^{B} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$ $\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$ $\vec{\mathbf{M}}^{B/P} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$ $\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$
B is molten (liquid metal)	No	$\vec{\mathbf{F}}^{B} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$ $\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$ $\vec{\mathbf{M}}^{B/P} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$ $\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$ $\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$

16.9 ♣ Measurement accuracies of the Universal Gravitational Constant G (Section 21.3).

The gravitational force on a particle Q of mass m^Q from a particle P of mass m^P can be written in terms of Q's position vector from P as

$$\vec{\mathbf{F}}^{Q/P} \underset{(21.3)}{=} \frac{-G\, m^P\, m^Q}{|\vec{\mathbf{r}}^{Q/P}|^3}\, \vec{\mathbf{r}}^{Q/P}$$

What are the dimensions of G (in terms of mass, length and time) and the SI units of G?

Result: Dimensions of G: (in terms of mass, length, time) ______ / ______   Units of G: (in terms of kg, m, s) ______ / ______

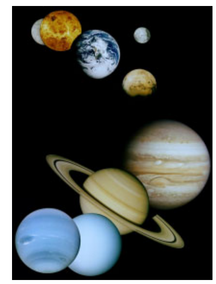
The number of significant digits the first measurement of the "***Universal Gravitational Constant***" G in 1798 by Cavendish and recent (year 2000^+) experiments of G are estimated to be accurate to:

Experiments in 1798	1	2	5	7	infinite
Experiments in 2000^+	1	2	5	7	infinite

Note: Section 21.3 discusses experiments involving G.

16.10 ♣ According to Newton's laws (theories), is the universe static? (Sections 18.2 and 19.3)

Consider the system S consisting of all matter, life, forces, etc.[a]



- Newton's laws dictates the resultant of all forces on S is $\vec{\mathbf{0}}$, i.e., $\vec{\mathbf{F}}^S = \vec{\mathbf{0}}$. **True/False**.
- The moment of all forces on S about any point P is $\vec{\mathbf{0}}$, i.e., $\vec{\mathbf{M}}^{S/P} = \vec{\mathbf{0}}$. **True/False**.
- Newton's laws dictates the universe is in **static equilibrium**. **True/False**.
- Newton's **$1^{st}/2^{nd}/3^{rd}$** law explains my answer? (circle one)

Why: ______

[a] Carbon 12 has $\approx 6.02 \times 10^{23}$ molecules. The universe has $\approx 10^{80}$ molecules.

16.11 ♣ Free-Body Diagrams for 3D three-balloon system.

The picture below shows a cup hanging by strings from three motionless helium-filled balloons. Draw ***FBDs*** of each system for the given assumptions.

Helium is lighter than air.

FBD of cup:	FBD of left string:	FBD of left balloon:
Assumptions in FBD Only relevant forces are Earth's uniform gravity and contact forces from strings (no wind/air resistance, electromagnetic forces, etc.)	**Assumptions in FBD** String is inextensible. Only relevant forces are tension in string (gravity/other forces are negligible compared to tension.)	**Assumptions in FBD** Relevant forces are gravity from Earth, fluid pressure from air (buoyancy), and contact from strings and other balloons.