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)	$1\ kg \cdot \frac{m}{s^2}$	$1\ slug \cdot \frac{ft}{s^2}$	$1\ lb_m \cdot \frac{ft}{s^2}$	
	$9.81\ kg \cdot \frac{m}{s^2}$	$9.81\ slug \cdot \frac{ft}{s^2}$	$9.81\ lb_m \cdot \frac{ft}{s^2}$	
	$32.2\ kg \cdot \frac{m}{s^2}$	$32.2\ slug \cdot \frac{ft}{s^2}$	$32.2\ lb_m \cdot \frac{ft}{s^2}$	

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

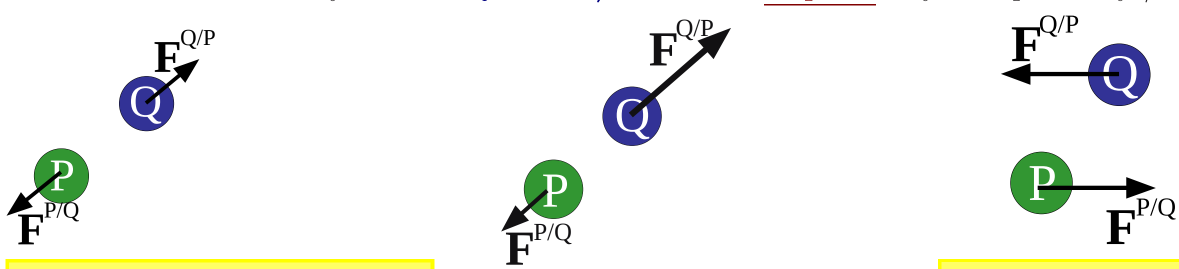
$$1\ \text{lbf} \approx \frac{\square\ \text{lbm ft}}{s^2} * \frac{\square\ \text{kg}}{\square\ \text{lbm}} * \frac{\square\ \text{inch}}{\square\ \text{ft}} * \frac{\square\ \square}{\square\ \square} * \frac{\square\ \square}{\square\ \square} * \frac{\square\ \text{N}}{\square\ \text{kg m/s}^2} \approx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

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 $0 \leq \mu_s \leq 1$. **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**
For $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ to be valid, the m in $m\,g$ must be exactly equal to the m in $m\,\vec{\mathbf{a}}$.	____
For Einstein's relativity to be valid, the m in $m\,g$ must be exactly equal to the m in $m\,\vec{\mathbf{a}}$.	____
For modern string theory to be valid, the m in $m\,g$ must be exactly equal to the m in $m\,\vec{\mathbf{a}}$.	____

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 x meters, 1 lbf (pound-force) to y Newtons, and 1 psi ($\frac{\text{lbf}}{\text{inch}^2}$) to z Pascals ($\frac{\text{N}}{\text{m}^2}$). Express results for z in terms of the intermediate conversion factors x and y.

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

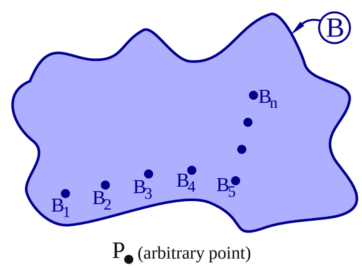
Conversion	Equation (with numbers and units) for calculating result.	
$1 \text{ in} = x \text{ m}$	$x = 1 \text{ in} * \frac{2.54 \text{ cm}}{1 \text{ in}} * \frac{1 \text{ m}}{100 \text{ cm}} \approx 0.0254$	Example of how to do units conversions
$1 \text{ lbf} = y \text{ N}$	$y =$ ______ ≈ 4.45	
$1 \text{ psi} = z \text{ Pa}$	$z =$ ______ ≈ 6894.757	Express z in terms of x and 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	Yes	$\vec{\mathbf{F}}^{B} = \vec{0}$	$\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$	$\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$	$\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$
(a thin ruler)		$\vec{\mathbf{M}}^{B/P} = \vec{0}$	$\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$	$\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$	$\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$
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	No	$\vec{\mathbf{F}}^{B} = \vec{0}$	$\vec{\mathbf{F}}^{B}_{\text{internal}} = \vec{0}$	$\vec{\mathbf{F}}^{B}_{\text{external}} = \vec{0}$	$\vec{\mathbf{F}}^{B_1/B_2} = \vec{0}$
(liquid metal)		$\vec{\mathbf{M}}^{B/P} = \vec{0}$	$\vec{\mathbf{M}}^{B/P}_{\text{internal}} = \vec{0}$	$\vec{\mathbf{M}}^{B/P}_{\text{external}} = \vec{0}$	$\vec{\mathbf{M}}^{\vec{\mathbf{F}}^{B_2/B_1}/P} = \vec{0}$

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 from P as

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

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) ______ / ______

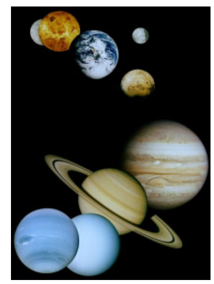
The number of significant digits the first measurement of the "***Universal Gravitational Constant***" G in 1798 by Cavendish and recent (year 2000^+) experiments of G are estimated to be accurate to:

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]

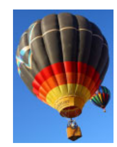


- Newton's laws dictates the resultant of all forces on S is $\vec{\mathbf{0}}$, i.e., $\vec{\mathbf{F}}^S = \vec{\mathbf{0}}$. **True/False**.
- The moment of all forces on S about any point P is $\vec{\mathbf{0}}$, i.e., $\vec{\mathbf{M}}^{S/P} = \vec{\mathbf{0}}$. **True/False**.
- Newton's laws dictates the universe is in **static equilibrium**. **True/False**.
- Newton's **1st/2nd/3rd** 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 ♣ FBDs (Free-Body Diagrams) for 3D three-balloon system.



The picture below shows a cup hanging from three light (massless) strings, which attach to a motionless helium-filled balloon. For each system, draw a ***FBD*** (use 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.