

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)	<input type="checkbox"/> $1 \frac{\text{kg m}}{\text{s}^2}$	<input type="checkbox"/> $9.81 \frac{\text{kg m}}{\text{s}^2}$	<input type="checkbox"/> $32.2 \frac{\text{kg m}}{\text{s}^2}$	<input type="checkbox"/> None of these
1 lb _f is defined as or approximately equal to (circle all that apply)	<input type="checkbox"/> $1 \text{ kg} \cdot \frac{\text{m}}{\text{s}^2}$	<input type="checkbox"/> $1 \text{ slug} \cdot \frac{\text{ft}}{\text{s}^2}$	<input type="checkbox"/> $1 \text{ lb}_m \cdot \frac{\text{ft}}{\text{s}^2}$	
	<input type="checkbox"/> $9.81 \text{ kg} \cdot \frac{\text{m}}{\text{s}^2}$	<input type="checkbox"/> $9.81 \text{ slug} \cdot \frac{\text{ft}}{\text{s}^2}$	<input type="checkbox"/> $9.81 \text{ lb}_m \cdot \frac{\text{ft}}{\text{s}^2}$	
	<input type="checkbox"/> $32.2 \text{ kg} \cdot \frac{\text{m}}{\text{s}^2}$	<input type="checkbox"/> $32.2 \text{ slug} \cdot \frac{\text{ft}}{\text{s}^2}$	<input type="checkbox"/> $32.2 \text{ lb}_m \cdot \frac{\text{ft}}{\text{s}^2}$	

Using the exact Section 21.1 NIST conversion factor for lb_m to kg and the exact conversion factor 1 inch ≜ 2.54 cm, show how to calculate the conversion factor for lb_f to Newton.

Result

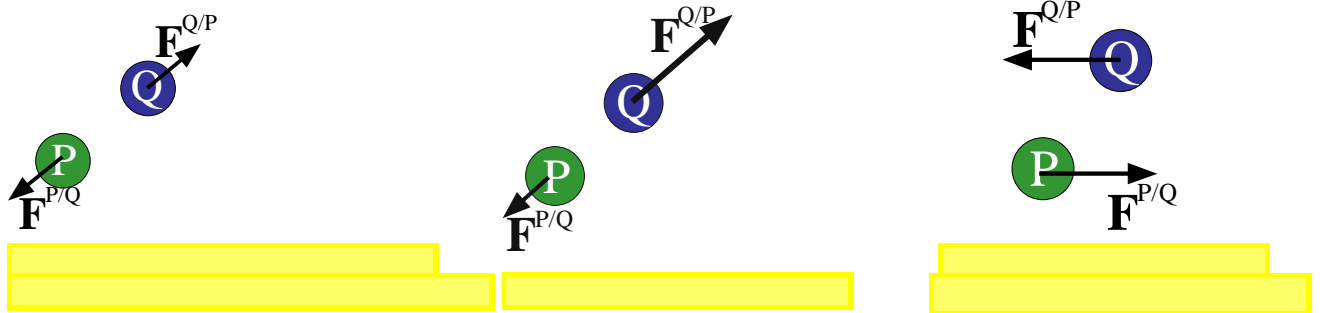
$$1 \text{ lb}_f \approx \frac{\text{lb}_m \text{ ft}}{\text{s}^2} * \frac{\text{kg}}{\text{lb}_m} * \frac{\text{inch}}{\text{ft}} * \frac{\text{m}}{\text{inch}} * \frac{\text{N}}{\text{kg m/s}^2} \approx 4.45 \text{ N}$$

16.3 ♣ Force concepts (Section 18.3).

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

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 (< 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.	<input type="text"/>
The center of gravity of a rigid body always exists.	<input type="text"/>
For $\vec{F} = m \vec{a}$ to be valid, the m in mg must be exactly equal to the m in $m \vec{a}$.	<input type="text"/>
For Einstein's relativity to be valid, the m in mg must be exactly equal to the m in $m \vec{a}$.	<input type="text"/>
For modern string theory to be valid, the m in mg must be exactly equal to the m in $m \vec{a}$.	<input type="text"/>

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 your results for **z** in terms of the intermediate conversion factors **x** and **y**.

$$1 \text{ inch} \triangleq 2.54 \text{ cm} \qquad 1 \text{ kg} \approx 2.2 \text{ lbf} \qquad 1 \text{ g}_{\text{Earth}} \approx 32.2 \frac{\text{ft}}{\text{s}^2}$$

Conversion Equation (with numbers and units) for calculating result.

1 in = x m	x = 1 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 = y N	y = 	\approx 4.45
1 psi = z Pa	z = 	Express z in terms of x and y

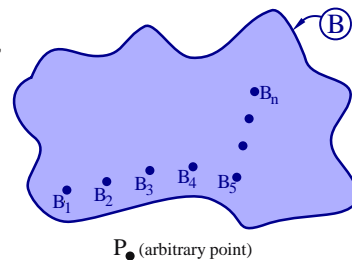
Engineering skill: Estimate/approximate order-of-magnitudes for mass, force, and stress.

Mass of a laptop computer	0.04/0.4/4/40/400	lbf
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 (\approx 27 grams) which define a body *B*. The quantities under investigation (and related moments) are:

- \vec{F}^B the resultant of all forces on *B*
- $\vec{F}_{\text{internal}}^B$ the resultant of all internal forces in *B*
- $\vec{F}_{\text{external}}^B$ the resultant of all external forces on *B*
- \vec{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.			
<i>B</i> is rigid	Yes	$\vec{F}^B = \vec{0}$	$\vec{F}_{\text{internal}}^B = \vec{0}$	$\vec{F}_{\text{external}}^B = \vec{0}$	$\vec{F}^{B_1/B_2} = \vec{0}$
		$\vec{M}^{B/P} = \vec{0}$	$\vec{M}_{\text{internal}}^{B/P} = \vec{0}$	$\vec{M}_{\text{external}}^{B/P} = \vec{0}$	$\vec{M}^{\vec{F}^{B_2/B_1}/P} = \vec{0}$
<i>B</i> is flexible (a thin ruler)	Yes	$\vec{F}^B = \vec{0}$	$\vec{F}_{\text{internal}}^B = \vec{0}$	$\vec{F}_{\text{external}}^B = \vec{0}$	$\vec{F}^{B_1/B_2} = \vec{0}$
		$\vec{M}^{B/P} = \vec{0}$	$\vec{M}_{\text{internal}}^{B/P} = \vec{0}$	$\vec{M}_{\text{external}}^{B/P} = \vec{0}$	$\vec{M}^{\vec{F}^{B_2/B_1}/P} = \vec{0}$
<i>B</i> is rigid	No	$\vec{F}^B = \vec{0}$	$\vec{F}_{\text{internal}}^B = \vec{0}$	$\vec{F}_{\text{external}}^B = \vec{0}$	$\vec{F}^{B_1/B_2} = \vec{0}$
		$\vec{M}^{B/P} = \vec{0}$	$\vec{M}_{\text{internal}}^{B/P} = \vec{0}$	$\vec{M}_{\text{external}}^{B/P} = \vec{0}$	$\vec{M}^{\vec{F}^{B_2/B_1}/P} = \vec{0}$
<i>B</i> is molten (liquid metal)	No	$\vec{F}^B = \vec{0}$	$\vec{F}_{\text{internal}}^B = \vec{0}$	$\vec{F}_{\text{external}}^B = \vec{0}$	$\vec{F}^{B_1/B_2} = \vec{0}$
		$\vec{M}^{B/P} = \vec{0}$	$\vec{M}_{\text{internal}}^{B/P} = \vec{0}$	$\vec{M}_{\text{external}}^{B/P} = \vec{0}$	$\vec{M}^{\vec{F}^{B_2/B_1}/P} = \vec{0}$

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

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

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

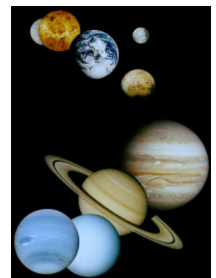
Note: Section 21.3 discusses experiments involving G .

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)

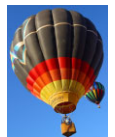
Why:



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

16.11 ♣ **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.

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