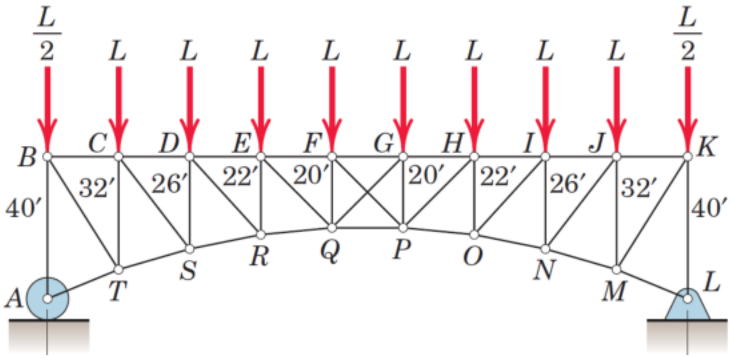

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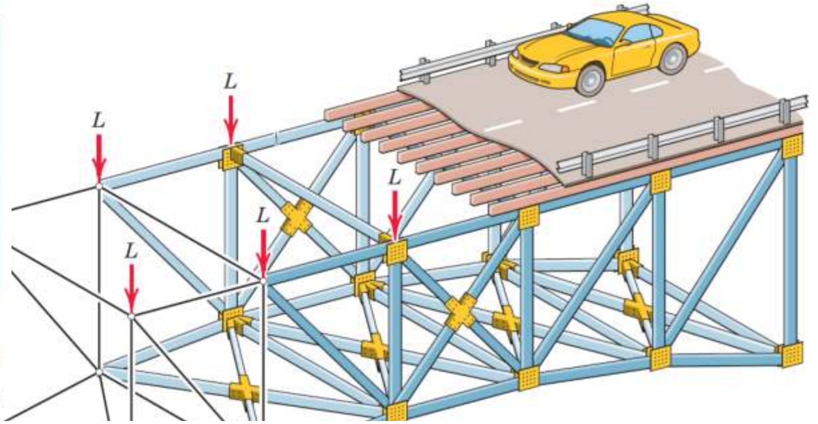
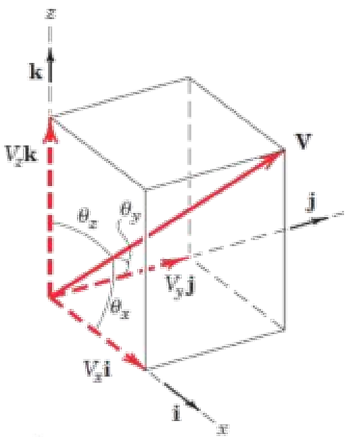


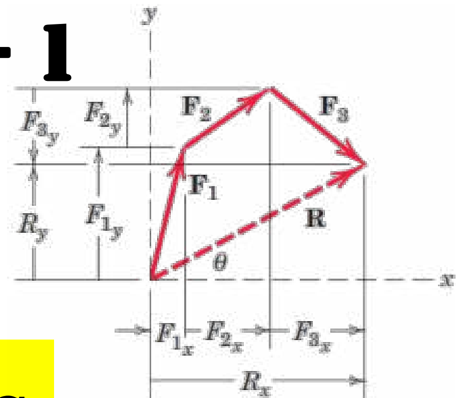


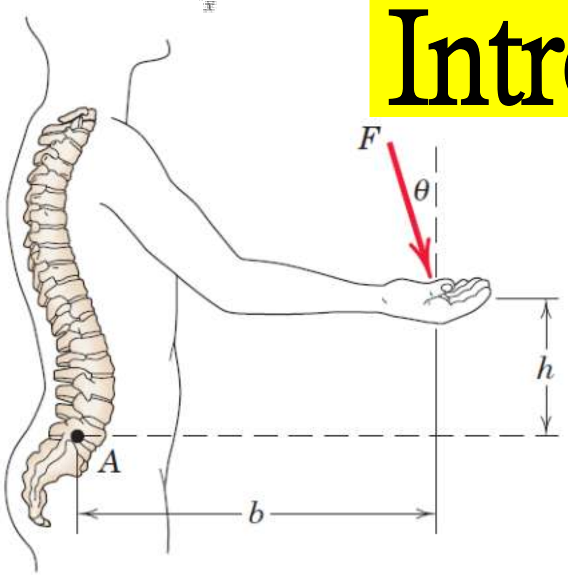
ENGINEERING MECHANICS – 1

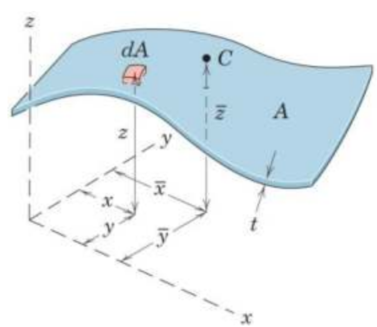
ENG 203

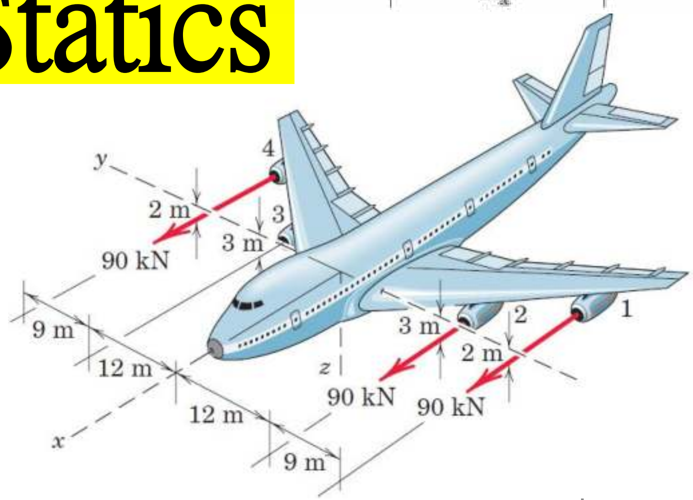
CHAPTER - 1

Introduction to Statics









University of Tabuk
Faculty of Engineering

2021 Academic Calendar

Semester 431

Week #	Dates	Note
1	29 Aug – 02 Sep	
2	05 Sep – 09 Sep	
3	12 Sep – 16 Sep	
4	19 Sep – 23 Sep	22-23 Sep – No Classes (National Day)
5	26 Sep – 30 Sep	Midterm I
6	03 Oct – 07 Oct	Midterm I
7	10 Oct – 14 Oct	Midterm I
8	17 Oct – 21 Oct	17 -18 Oct – No Classes (Long Weekend)
9	24 Oct – 28 Oct	
10	31 Oct – 04 Nov	04 Nov – No Classes (Long Weekend)
11	07 Nov – 11 Nov	Midterm II
12	14 Nov – 18 Nov	Midterm II
13	21 Nov – 25 Nov	Midterm II
14	28 Nov – 02 Dec	28 Nov – 02 Dec - No Classes (Fall Break)
15	05 Dec – 09 Dec	
16	12 Dec – 16 Dec	
17	19 Dec – 23 Dec	19 Dec – No Classes (Long Weekend) – Final Exam
18	26 Dec – 30 Dec	Final Exam
19	02 Jan – 06 Jan	Final Exam

Evaluation Methods

Quizzes and Homeworks :	20 %
Exam Midterm 1 :	20 %
Exam Midterm 2 :	20 %
Final exam:	40 %

Textbook & Reference

J.M. Meriem and J. E. Kraige

“Engineering Mechanics : Statics”, 7th edition

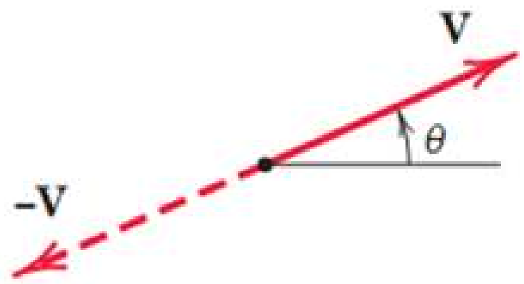
CHAPTER OUTLINE

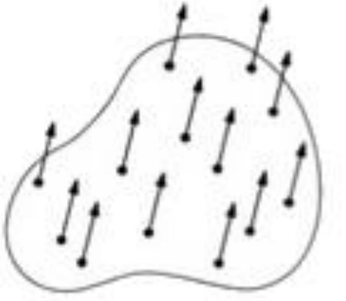
- ✓ *Scalars and Vectors*
- ✓ *Newton's Laws*
- ✓ *Units*
- ✓ *Law of Gravitation*
- ✓ *Exercises*

Scalars and Vectors

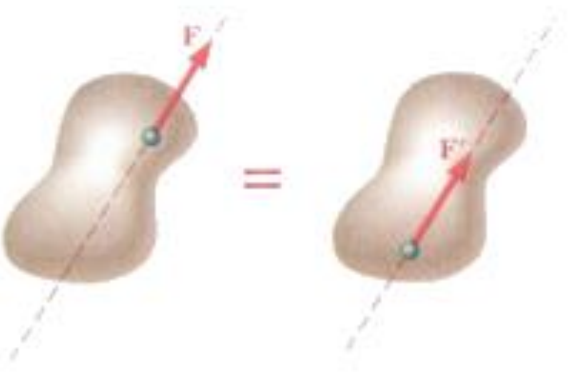
There are three specifications for each vector:

- ✓ ***Magnitude,***
- ✓ ***Direction**, and*
- ✓ ***Point of application**.*

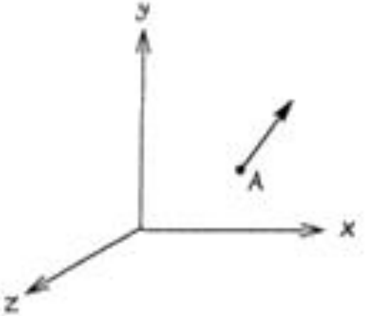




A free vector is one whose action is not confined to or associated with a unique line in space.



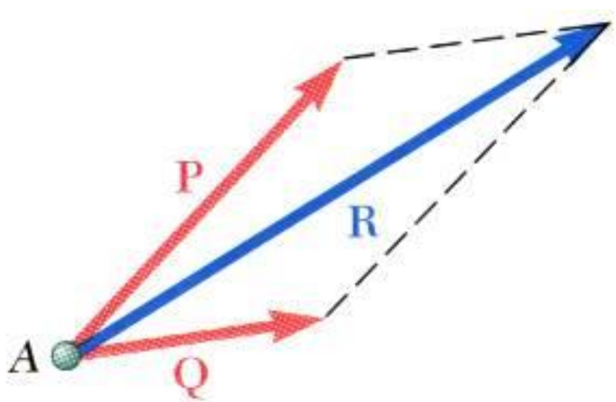
A sliding vector has a unique line of action in space but not a unique point of application.



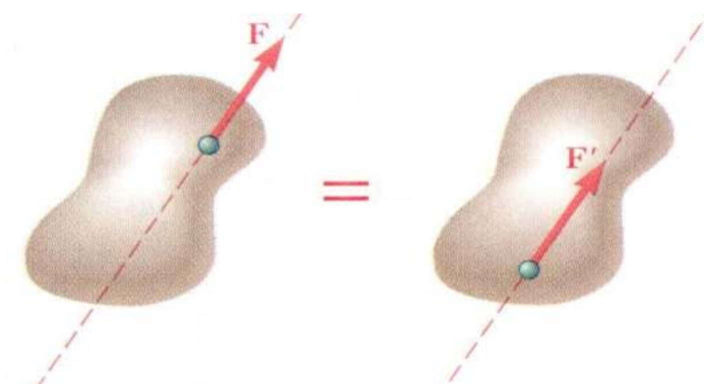
A fixed vector is one for which a unique point of application is specified.

Parallelogram Law & Principle of Transmissibility

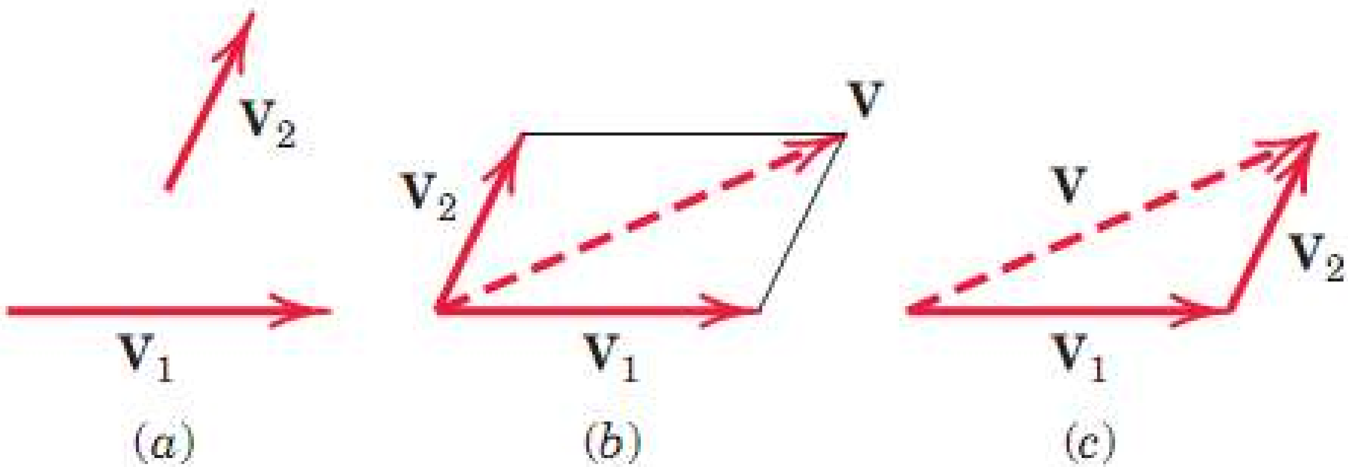
Parallelogram Law



Principle of Transmissibility

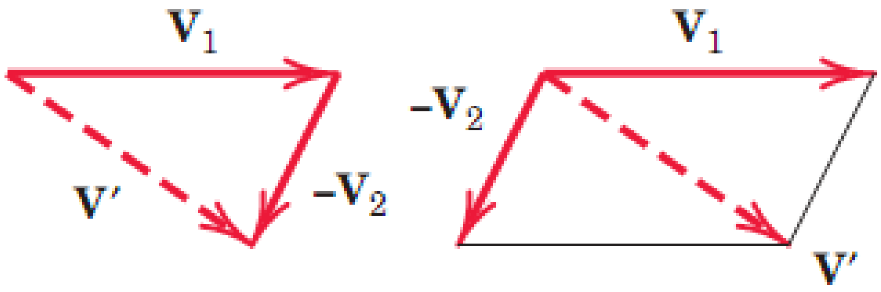


Resultant of two vectors using **Parallelogram Law**

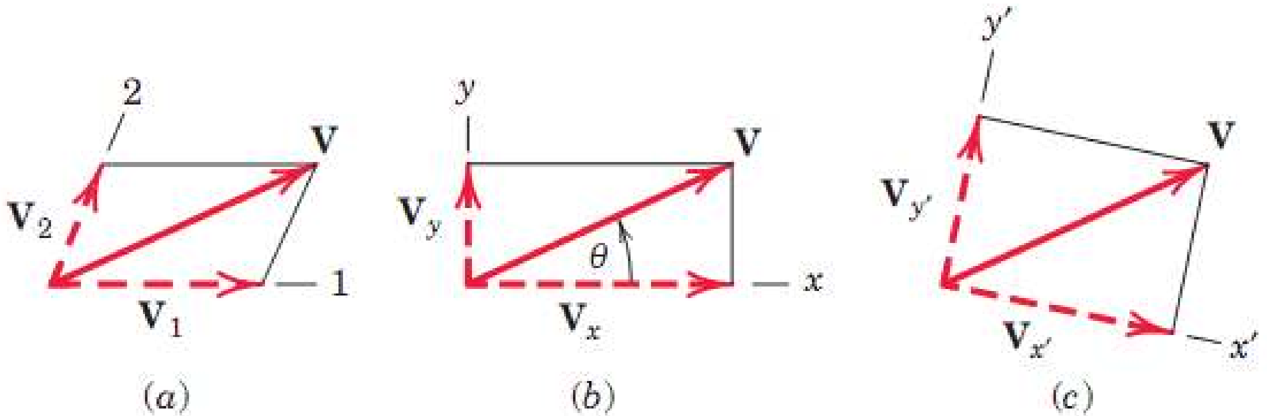


$$\mathbf{V} = \mathbf{V}_1 + \mathbf{V}_2$$

Resultant of two vectors using **Parallelogram Law**



$$\mathbf{V}' = \mathbf{V}_1 - \mathbf{V}_2$$



$$\theta = \tan^{-1} \frac{V_y}{V_x}$$

Newton's Laws

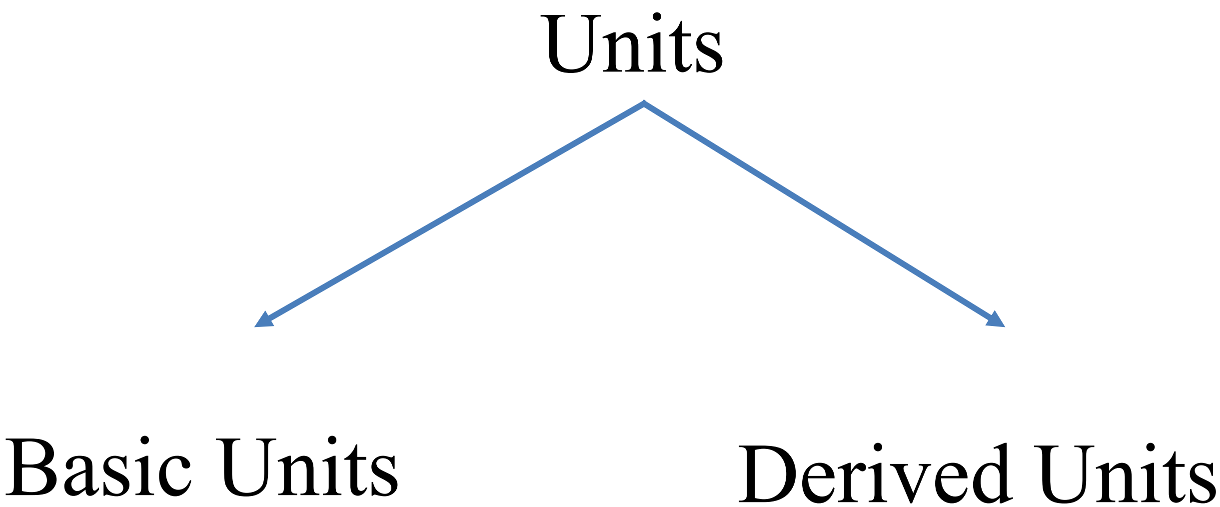
- ***Newton's First Law***: If the resultant force on a particle is zero, the particle will remain at rest or continue to move in a straight line.

- ***Newton's Second Law***: A particle will have an acceleration proportional to a nonzero resultant applied force.

$$\boldsymbol{F = m \cdot a}$$

- ***Newton's Third Law***: The forces of action and reaction between two particles have the same magnitude and line of action with **opposite sense**.

Systems of Units



Systems of Units

***International System of Units* (SI):**

The **basic units** are **Length, Time**, and **Mass** which are arbitrarily defined as the meter (***m***), second (***s***), and kilogram (***kg***).

Force is the derived unit:

$$F = ma$$

$$1\,\text{N} = (1\,\text{kg})\left(1\,\frac{\text{m}}{\text{s}^2}\right)$$

U.S. Customary Units:

The **basic units** are **Length**, **Time**, and **Force** which are randomly defined as the foot (***ft***), second (***s***), and pound (***lb***). Mass is the derived unit,

$$m = \frac{F}{a}$$

$$1\,\text{slug} = \frac{1\,\text{lb}}{1\,\text{ft/s}^2}$$

SI Units *vs.* U.S. Customary Units

Gravitational force is the weight W of the body, and is found from:

$$W\ (\text{N}) = m\ (\text{kg}) \times g\ (\text{m/s}^2)$$

The MKS (meter, kilogram, second): $\text{N} = \text{kg} \cdot \text{m/s}^2$

$$m\ (\text{slugs}) = \frac{W\ (\text{lb})}{g\ (\text{ft/sec}^2)} \quad \Rightarrow \quad \text{slug} = \frac{\text{lb} \cdot \text{sec}^2}{\text{ft}}$$

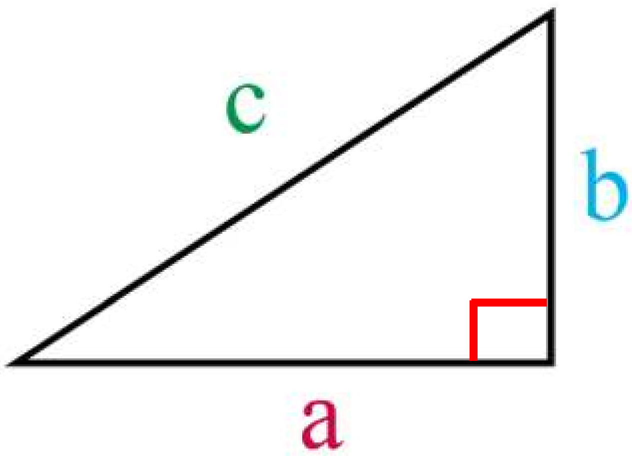
SI units	$g = 9.806\ 65\ \text{m/s}^2$
U.S. units	$g = 32.1740\ \text{ft/sec}^2$

Changing units from one system to another:

- ✓ ***1** ft. **= 0.3048** m*
- ✓ ***1** slug **= 14.59** kg*
- ✓ ***1** lb. **= 4.448** N*

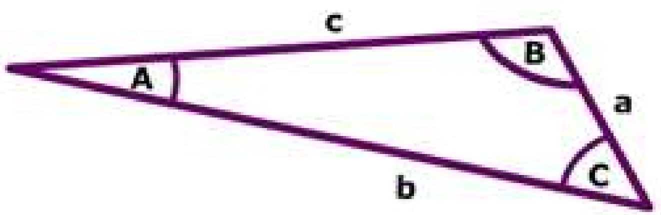
Addition of Vectors

Pythagorean Theorem:



$$a^2 + b^2 = c^2$$

Addition of Vectors

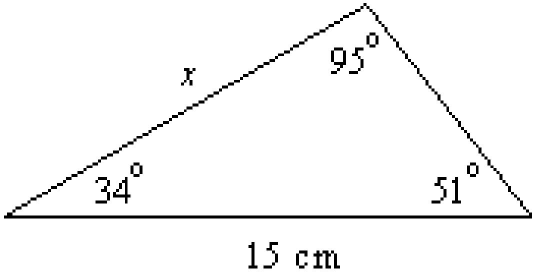


Law of sines

$$\frac{\sin(A)}{a} = \frac{\sin(B)}{b} = \frac{\sin(C)}{c}$$

or: $$\frac{a}{\sin(A)} = \frac{b}{\sin(B)} = \frac{c}{\sin(C)}$$

Example:

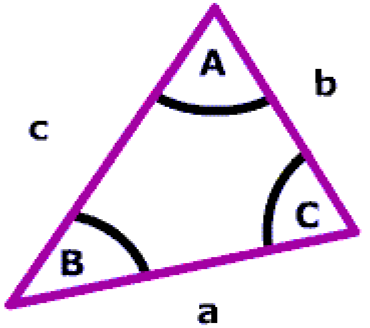


$$\frac{\sin 51°}{x} = \frac{\sin 95°}{15}$$

$$x \sin 95° = 15 \sin 51°$$

$$x = \frac{15 \sin 51°}{\sin 95°} = 11.7017$$

Law of cosines



$$a^2 = b^2 + c^2 - 2bc \cdot \cos(A)$$

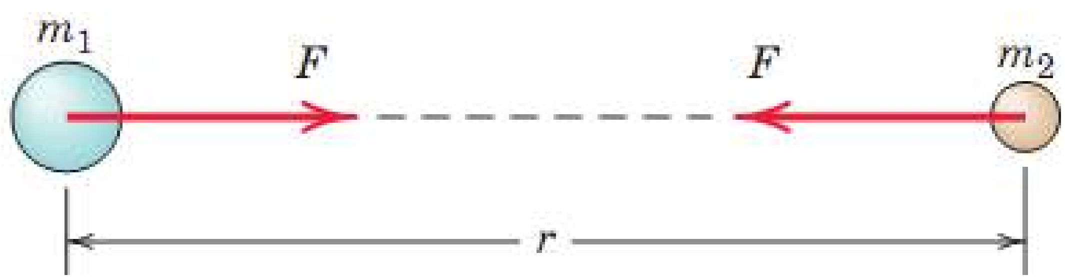
$$b^2 = a^2 + c^2 - 2ac \cdot \cos(B)$$

$$c^2 = a^2 + b^2 - 2ab \cdot \cos(c)$$

Law of Gravitation

Newton's Law of Gravitation: Two particles are attracted with equal and opposite forces,

$$F = G\frac{m_1 m_2}{r^2} \qquad W = mg, \quad g = \frac{GM}{R^2}$$



where:
F: *the mutual force of attraction between two particles*
G: *a universal constant known as the* ***<u>constant of gravitation</u>***
$\boldsymbol{m_1, m_2}$**:** the masses of the two particles
r: *the distance between the* ***<u>centers of the particles</u>***

By experiment the gravitational constant is found to be **G:**

$$G = 6.673(10^{-11})\ \mathrm{m^3/(kg\cdot s^2)}$$

Solar System Constants

TABLE D/2 SOLAR SYSTEM CONSTANTS

Universal gravitational constant	$G = 6.673(10^{-11})\ m^3/(kg \cdot s^2)$
	$= 3.439(10^{-8})\ ft^4/(lbf\text{-}s^4)$
Mass of Earth	$m_e = 5.976(10^{24})$ kg
	$= 4.095(10^{23})\ lbf\text{-}s^2/ft$
Period of Earth's rotation (1 sidereal day)	= 23 h 56 min 4 s
	= 23.9344 h
Angular velocity of Earth	$\omega = 0.7292(10^{-4})$ rad/s
Mean angular velocity of Earth–Sun line	$\omega' = 0.1991(10^{-6})$ rad/s
Mean velocity of Earth's center about Sun	= 107 200 km/h
	= 66,610 mi/h

BODY	MEAN DISTANCE TO SUN km (mi)	ECCENTRICITY OF ORBIT e	PERIOD OF ORBIT solar days	MEAN DIAMETER km (mi)	MASS RELATIVE TO EARTH	SURFACE GRAVITATIONAL ACCELERATION m/s^2 (ft/s^2)	ESCAPE VELOCITY km/s (mi/s)
Sun	—	—	—	1 392 000 (865 000)	333 000	274 (898)	616 (383)
Moon	384 398[1] (238 854)[1]	0.055	27.32	3 476 (2 160)	0.0123	1.62 (5.32)	2.37 (1.47)
Mercury	57.3×10^6 (35.6×10^6)	0.206	87.97	5 000 (3 100)	0.054	3.47 (11.4)	4.17 (2.59)
Venus	108×10^6 (67.2×10^6)	0.0068	224.70	12 400 (7 700)	0.815	8.44 (27.7)	10.24 (6.36)
Earth	149.6×10^6 (92.96×10^6)	0.0167	365.26	12 742[2] (7 918)[2]	1.000	9.821[3] (32.22)[3]	11.18 (6.95)
Mars	227.9×10^6 (141.6×10^6)	0.093	686.98	6 788 (4 218)	0.107	3.73 (12.3)	5.03 (3.13)
Jupiter[4]	778×10^6 (483×10^6)	0.0489	4333	139 822 86 884	317.8	24.79 (81.3)	59.5 (36.8)

Exercises

EXERCISE - 1

Determine the *weight in newtons* of a car whose *mass is **1400 kg***. *Convert the mass of the car to slugs* and then determine its *weight in pounds*.

Solution – Exercise - 1

SI units	$g = 9.806\,65 \text{ m/s}^2$
U.S. units	$g = 32.1740 \text{ ft/sec}^2$

Changing units from one system to another:

- ✓ ***1*** *ft.* = ***0.3048*** *m*
- ✓ ***1*** *slug* = ***14.59*** *kg*
- ✓ ***1*** *lb.* = ***4.448*** *N*

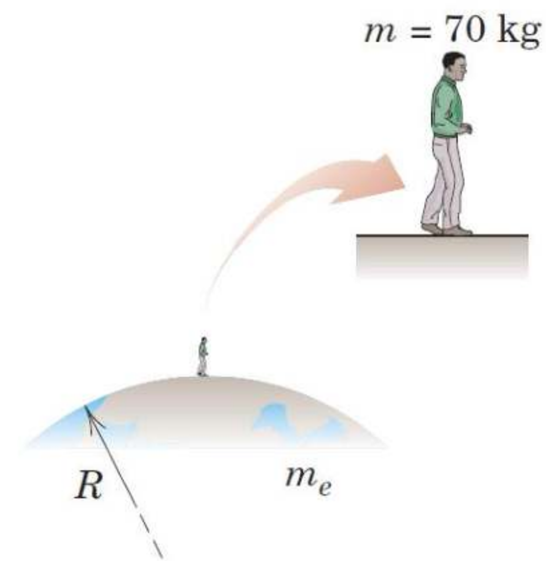
1. $$W = mg = 1400(9.81) = 13\,730 \text{ N}$$

2. $$m = 1400 \text{ kg}\left[\frac{1 \text{ slug}}{14.594 \text{ kg}}\right] = 95.9 \text{ slugs}$$

3. $$W = mg = (95.9)(32.2) = 3090 \text{ lb}$$

EXERCISE - 2

Use Newton's law of universal gravitation to calculate the weight of a **70-kg** person standing on the surface of the earth. Then repeat the calculation by using: ***W* = *m* . *g*** and compare your two results.



Mass of Earth $m_e = 5.976(10^{24})$ kg

$$G = 6.673(10^{-11})\ \text{m}^3/(\text{kg}\cdot\text{s}^2) = 3.439(10^{-8})\ \text{ft}^4/(\text{lbf-s}^4)$$

The **diameter** of the earth = **12742 Km**

Solution – Exercise - 2

1

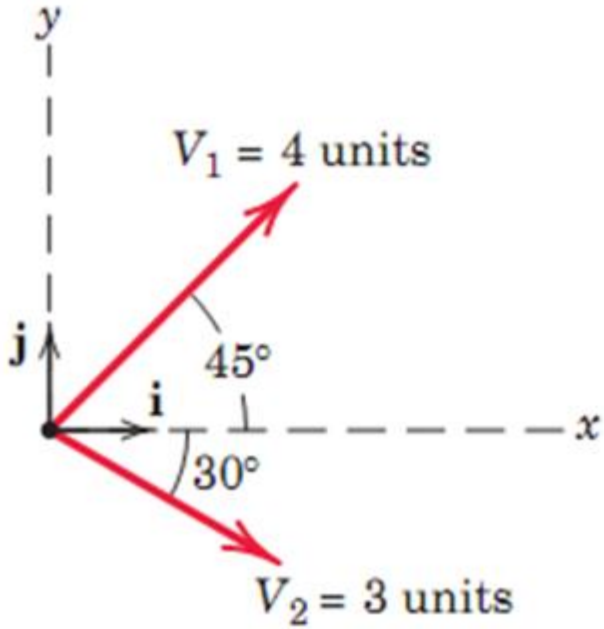
$$W = \frac{Gm_e m}{R^2} = \frac{(6.673\cdot 10^{-11})(5.976\cdot 10^{24})(70)}{[6371\cdot 10^3]^2} = 688\ \text{N}$$

$$W = mg = 70(9.81) = 687\ \text{N}$$

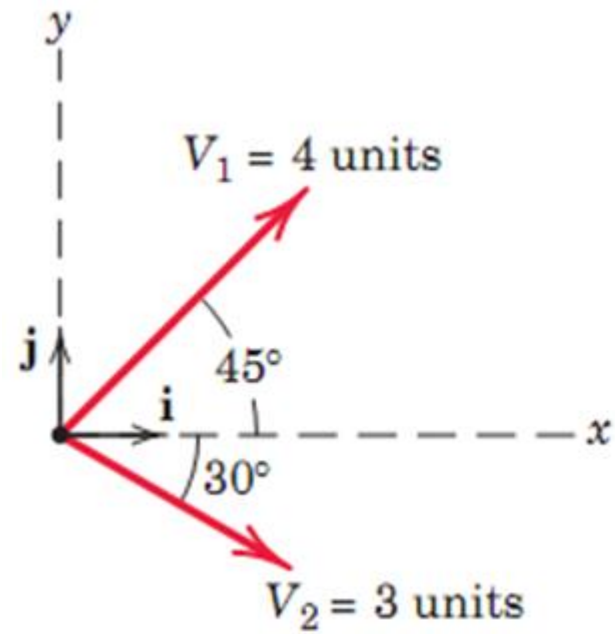
EXERCISE - 3

For the vectors $\boldsymbol{V_1}$ and $\boldsymbol{V_2}$ shown in the figure,

1. *Determine the magnitude* **S** *of their vector sum* $\boldsymbol{S} = \boldsymbol{V_1} + \boldsymbol{V_2}$
2. *Determine the angle between* **S** *and the* ***positive x-axis***
3. *Write* **S** *as a vector in terms of the unit vectors* ***i*** *and* ***j*** *and then write a unit vector* ***n*** *along the vector sum* **S**
4. *Determine the vector difference* $\boldsymbol{D} = \boldsymbol{V_1} - \boldsymbol{V_2}$



EXERCISE - 3

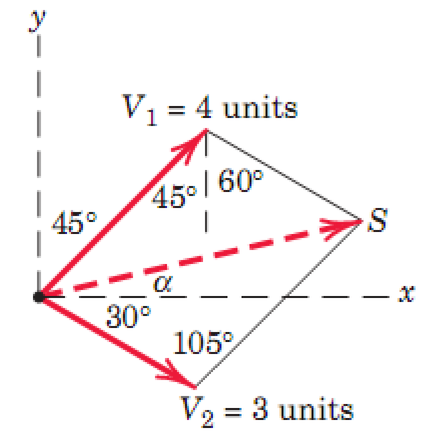


Solution – Exercise - 3

Solution (*a*) We construct to scale the parallelogram shown in Fig. *a* for adding $\mathbf{V}_1$ and $\mathbf{V}_2$. Using the law of cosines, we have

$$S^2 = 3^2 + 4^2 - 2(3)(4)\cos 105°$$

$$S = 5.59 \text{ units} \qquad \textit{Ans.}$$



(*a*)

1 (*b*) Using the law of sines for the lower triangle, we have

$$\frac{\sin 105°}{5.59} = \frac{\sin(\alpha + 30°)}{4}$$

$$\sin(\alpha + 30°) = 0.692$$

$$(\alpha + 30°) = 43.8° \qquad \alpha = 13.76° \qquad \textit{Ans.}$$

(*c*) With knowledge of both S and α, we can write the vector $\mathbf{S}$ as

$$\mathbf{S} = S[\mathbf{i}\cos\alpha + \mathbf{j}\sin\alpha]$$

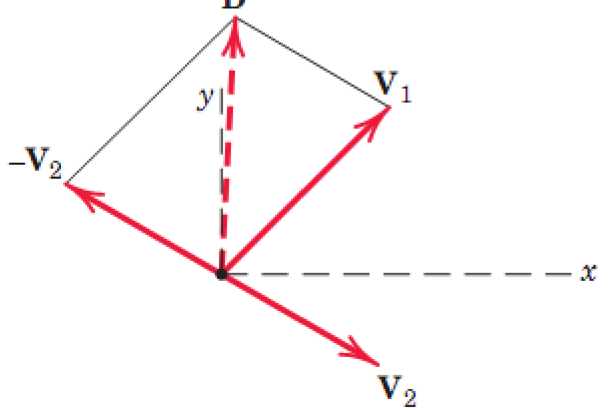
$$= 5.59[\mathbf{i}\cos 13.76° + \mathbf{j}\sin 13.76°] = 5.43\mathbf{i} + 1.328\mathbf{j} \text{ units} \qquad \textit{Ans.}$$

2 Then $\mathbf{n} = \dfrac{\mathbf{S}}{S} = \dfrac{5.43\mathbf{i} + 1.328\mathbf{j}}{5.59} = 0.971\mathbf{i} + 0.238\mathbf{j}$ *Ans.*

(*d*) The vector difference $\mathbf{D}$ is

$$\mathbf{D} = \mathbf{V}_1 - \mathbf{V}_2 = 4(\mathbf{i}\cos 45° + \mathbf{j}\sin 45°) - 3(\mathbf{i}\cos 30° - \mathbf{j}\sin 30°)$$

$$= 0.230\mathbf{i} + 4.33\mathbf{j} \text{ units} \qquad \textit{Ans.}$$



(*b*)

The vector $\mathbf{D}$ is shown in Fig. *b* as $\mathbf{D} = \mathbf{V}_1 + (-\mathbf{V}_2)$.

EXERCISE - 4

- 1/6) From the gravitational law calculate the weight W (gravitational force with respect to the earth) of a 80-kg man in a spacecraft traveling in a circular orbit 250 km above the earth's surface. Express W in both newtons and pounds.

$$m_e = 5.976(10^{24})\ \text{kg}$$

$$G = 6.673(10^{-11})\ \text{m}^3/(\text{kg}\cdot\text{s}^2)$$
$$= 3.439(10^{-8})\ \text{ft}^4/(\text{lbf-s}^4)$$

The **diameter** of the earth = **12742 Km**

Solution – Exercise - 4

1/6 $F = W = \dfrac{Gm_1m_2}{r^2}$,

where $G = 6.673(10^{-11})\ m^3/(kg \cdot s^2)$

$m_1 = 80\ kg$

$m_2 = 5.976(10^{24})\ kg$

and $r = (6371 + 250)(10^3)\ m$

Substitute these numbers & obtain $\underline{W = 728\ N}$

U.S. units : $W = 728\,N\left(\dfrac{1\ lb}{4.4482\ N}\right) = \underline{163.6\ lb}$

EXERCISE - 5

- 1/7) Determine the weight in newtons of a woman whose weight in pounds is 130. Also, find her mass in slugs and in kilograms.
- Solution:

1/7

$$W = (130\ \text{lb})\left(\frac{4.4482\ \text{N}}{\text{lb}}\right) = \underline{578\ \text{N}}$$

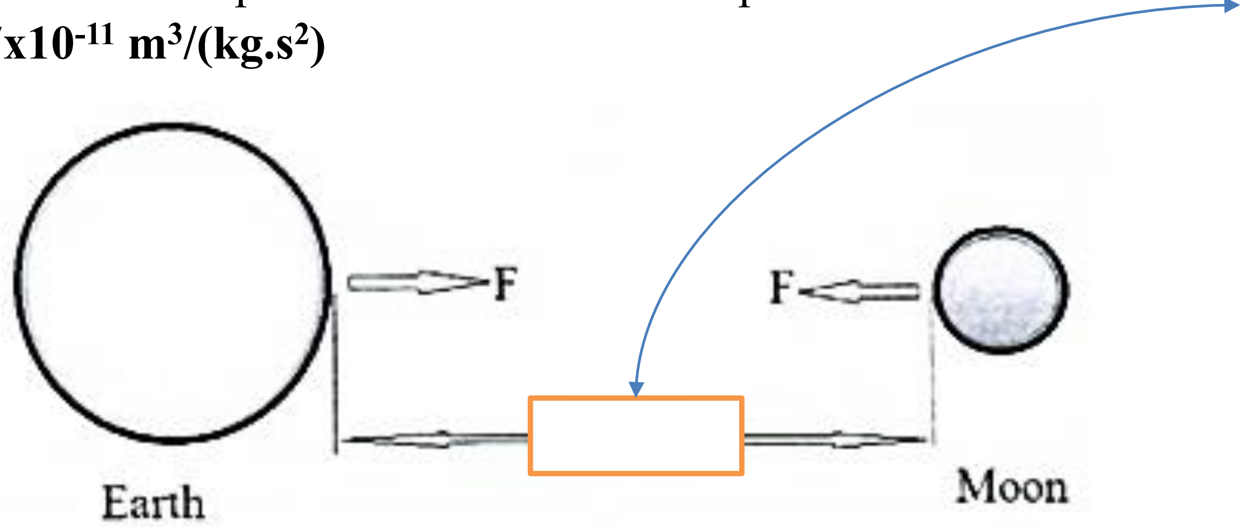
$$m = \frac{W}{g} = \frac{130}{32.2} = \underline{4.04\ \text{slugs}}$$

$$m = \frac{W}{g} = \frac{578}{9.81} = \underline{58.9\ \text{kg}}$$

EXERCISE - 6

- 1/9) Compute the magnitude F of the force which the earth exerts on the moon. Perform the calculation first in newtons and then convert your result to pounds.
- The moon's mass is 0.0123 relative to earth (or 7.35 x 10^{22} kg).

- **m_{moon}= 7.35x10^{22} kg**
- **m_{earth} = 5.9765x10^{24} kg**
- The **diameter** of the **earth = 12742 km**
- The **diameter** of the **moon = 3476 km**
- Distance from the top surface of the earth to top surface of the moon is **376289 km**
- **G= 6.67x10^{-11} $m^3/(kg.s^2)$**



Solution – Exercise - 6

1/9

$$F = \frac{G m_e m_m}{r^2} = \frac{6.673(10^{-11})(5.976 \cdot 10^{24})^2(1)(0.0123)}{(384\,398 \cdot 10^3)^2}$$

$$= \underline{1.984(10^{20})\ \text{N}}$$

$$F = 1.984(10^{20})\ \text{N}\left(\frac{1\ \text{lb}}{4.4482\ \text{N}}\right) = \underline{4.46(10^{19})\ \text{lb}}$$