Kinematics

Motion can be defined as a continuous change of position (*or* a change in position in time).

How do we know if an object is in motion?

>Motion is with respect to;

1) reference point - A change of position of an object in regards to the position of another object. This helps us to envision the magnitude of the speed of the object, as well as its direction of motion. Although a reference point can be stationary or in motion, stationary objects attached to the earth are best.

Relative to what?

- walking at 2 mph forward on an open train car moving at 60 mph = 62 mph
- walking at 2 mph backward on an open train car moving at 60 mph = 58 mph
- motion on a tredmill or stairmaster?

*Observers can only detect their uniform motion relative to stationary objects, but what objects are at rest?

*Prior to the arrival of Einstein's 1905 theory of special relativity, an "absolute reference frame" was thought to exist, but there is nothing at "absolute rest." If then all things are in motion, what do we use as a fixed standard for making comparisons? Einstein claims that such a standard cannot exist anywhere in the universe, and that the real magnitude or direction of motion of a body can not be known.

*Even Galileo had stated "*everything moves*."

*Absolute motion is the "true" motion with respect to absolute rest.

*There is no "true" measure for motion because there is no fixed point from which to calculate it.

ex; A uniformly moving train is moving eastward at 60 ft/s. The length of a car is 40 feet long and two peopleat opposite ends of the car throw a ball to each other at 40 ft/s. [Note that the forward motion of the ball is not affected by the motion of the train.] To an observer outside the train who only views the ball sees the ball moving forward at 60 ft/s + 40 ft/s = 100 ft/s. Another observer in a train moving on the other track is moving in the westward direction at 60 ft/s and views only the ball and not the train. Since the trains are moving away from each other at 120 ft/s, then even the ball at rest in the train would appear to be moving at 120 ft/s. When the ball is thrown from the front of the train to the rear the ball appears to the observer on the westbound train to be moving at 160 ft/s. Of course the motion of the earth on its axis, the motion of the earth in its orbit, the motion of the sun around our galaxy, and the motion of our galaxy in the universe would further change the apparent speed of the ball. What is the actual speed and direction of the ball?

*__Each measure appears true only for the observer who made it__.

*__One reference frame is not more valid than another__.

*__No preferred reference frame exists__, **as there is no object or reference frame which is at** "**absolute rest**."

*One frame of reference is as valid as another, as one can not tell which reference frame is moving, but only that both frames are moving with respect to each other.

2) time - "blink of an eye" *or* "a glacial pace" [ex; continental drift]

>Motion can be uniform or variable.

uniform motion - When an object passes through uniform amounts of distance in equal amounts of time, or at a "constant" speed.

variable motion - When an object's speed varies with time. [fast - stop - slow. ex; delivery truck in rush hr.]

How is motion measured?

1) <u>speed</u> of travel

speed = $^{\text{displacement}}/_{\text{time}}$ [units!] "per" = for each

displacement : A change in position measured in length (cm, m, km. etc..) "change of" $X = X_f - X_i$

2) <u>direction</u> of travel uses a compass rose: bearing & direction ----> 135˚ SE]

How do speed and velocity differ?

>The definition of speed says nothing about direction! Velocity, because it does have direction, is known as a "vector" property. Speed, which only expresses the magnitude of speed, and not having any direction is known as a "scalar" property.

Scalar & Vector quantities:

<u>scalar</u> - *Ltn*. "of a ladder" Some descriptions of physical quantities (matter or events) can be completely described in terms of their "magnitude," and *these quantities do <u>not</u> involve the idea of direction!*

*Measurements that have magnitude only (number and unit) are known as <u>scalar</u> quantities. They can be added or subtracted by simple arithmetic. [ex; 10 g + 4 g = 14 g *<u>or</u>* 20 s - 8 s = 12 s]
[ex.'s; length, mass, time, volume, density, speed, work, energy, power]

*length of arrow (vector) = scalar property

<u>vector</u> - *Ltn*. "to carry" Other descriptions of physical quantities can <u>only</u> be *completely* described if <u>direction</u> is also given, and are known as "directed" quantities.

ex; A person walks 2 km east. This event can be described by a vector which is an arrow whose length is proportional to its magnitude, and indicates the direction of the quantity.

*The <u>direction</u> <u>of</u> <u>arrow</u> = vector property, and the <u>length</u> <u>of</u> <u>an</u> <u>arrow</u> = scalar property.

*Measurements that have both magnitude and direction and are known as <u>vector</u> quantities.
[ex; displacement in the X-direction, a downward force, velocity in the NE direction, a clockwise torque, an upward acceleration]

*"Length" is used instead of "displacement" when direction of distance is not essential.

velocity - like speed, it indicates how rapidly the position of an object has changed during some time period
being a vector quantity, <u>it</u> <u>has</u> <u>direction</u> [$v = {}^{d}/_{t}$]
indicates the magnitude of speed <u>and</u> the direction
Therefore, speed = magnitude of velocity.

How does <u>average</u> and <u>instantaneous</u> velocity differ?

-Average velocity does not give any information about the speed at any one moment.

-Instantaneous velocity is the speed at an exact moment (like a speed limit sign), representing the limit of time as it approaches zero. A radar gun used by the police measures instantaneous velocity.

Questions:

ex.1: A sprinter runs 400 meters in 45 seconds. What is the "average velocity" of this runner?
note! We do not know what was happening between the starting and finishing points.

sol: v = $^{\text{total displacement}}/_{\text{total time}}$ ---> $^{400\text{ m}}/_{45\text{ s}}$ = **8.9 m/s**

ex.2: What is the average velocity of a runner who covers 26.2 miles in $2^h\ 6^m$?

sol: v = $^d/_t$ = $^{26.2\text{ mi.}}/_{126\text{ min.}}$ ~ $^{0.2\text{ mi.}}/_{\text{min.}}$ x $(^5/_5)$ ~ $^{\mathbf{1.0\text{ mi.}}}/_{\mathbf{5\text{ min.}}}$ [current mile record = 3^m:43.13^s**!**]

ex.3: A driver sneezes while driving at 27 m/s (60 mph). If her eyes were closed for 0.5 seconds, then how far did she travel with her eyes closed?

sol: d = v x t = 27 m/s x 0.5 s = **13.5 m**

This is in addition to a reaction time (~ 0.75 s) to apply brakes, and then begin stopping. [See handout.]

ex.4: How long would a person need to run at 3 m/s in order to cover 400 meters of distance?

sol: t = $^d/_v$ = $^{400\text{ m}}/_{3\text{ m/s}}$ = **133 s** [show units; "invert the denominator and multiply"]

ex.5: Sound (@ 20˚C) travels 1,127 ft/s (343 m/s). If an observer sees a lightning flash and hears the thunder 6 seconds later, then how far away was the lightning bolt?

sol: d = v x t = 343 m/s x 6 s = **2,058 m**

ex.6: A bicycle rider moving at 4 m/s rides for 15 minutes. How much distance was covered?

sol: Convert minutes to seconds. d = v x t = 4 m/s x 900 s = **3,600 m**

ex.7: A baseball is thrown at 90 mph. How much time does it take the ball to reach the batter 60 feet away?

sol: Convert mph to ft/s. ----> 90 $^{\text{mi.}}/_h$ $(^{1\text{ h}}/_{3{,}600\text{ s}})(^{5{,}280\text{ ft}}/_{1\text{ mi.}})$ = 132 ft/s

t = $^d/_v$ = $^{60\text{ ft}}/_{132\text{ ft/s}}$ = **0.45 s**

ex.8: The speed of light is 300,000,000 m/s. How long does it take light to reach the earth from the sun, which is 1.5 x 10^{11} m away?

sol: t = $^d/_v$ = $^{1.5 \times 10^{11}\text{ m}}/_{3.0 \times 10^8\text{ m/s}}$ = **500 s**

ex.9: A train travels 540 km in 4.5 hours. How far will it go in 8 hours at its average speed?
How long will it take travel 200 km at this speed?

sol: v = $^d/_t$ = $^{540\text{ km}}/_{4.5\text{ h}}$ = 120 km/h

d = v x t = 120 km/h x 8 h = **960 km**

t = $^d/_v$ = $^{200\text{ km}}/_{120\text{ km/h}}$ = **1.6 h** (*or* **96 min**.)

ex.10: A truck moving at 12 m/s increases its speed (uniformly) to 20 m/s during a time of 5 seconds.
Is the velocity constant? -----> No, velocity is changing!

acceleration (a) occurs when the velocity changes with time.
It is a way of indicating how much the velocity is changing during some time period.
It is the time rate of change of velocity -----> how fast does "how fast" change?

This concept was first introduced in 1620 by Galileo from his observations of rolling balls down an inclined plane.

How do we calculate acceleration?

$$a = \text{change in velocity} / \text{change in time} = v_f - v_i / t_2 - t_1$$

note! This relationship is useful for linear motion.

If an object moves along a curved path at constant speed, its direction is constantly changing, and therefore its "velocity" is changing ..... thus, it accelerates.

*A change in velocity occurs when either the speed or direction changes. [ex; circular motion]

ex.11: a) What is the acceleration of the truck (in question #10)?

sol: $a = 20\text{ m/s} - 12\text{ m/s} / 5\text{ s} = 8\text{ m/s} / 5\text{ s}$ -----> **1.6 m/s^2**

b) If velocity decreases from 20 m/s to 10 m/s in 5 seconds. Find its acceleration in this time interval.

sol: $a = 10\text{ m/s} - 20\text{ m/s} / 5\text{ s} = -10\text{ m/s} / 5\text{ s}$ -----> **-2.0 m/s^2**

c) If the truck decelerates at a rate of -2 m/s^2, what time is spent slowing from 20 m/s to 14 m/s?

sol: using acceleration (a) = $\Delta v / \Delta t$ ----> $\Delta t = \Delta v / a = 14\text{ m/s} - 20\text{ m/s} / -2\text{ m/s}^2$ = **3 s**

>Another example of acceleration is when an object falls toward the earth with only the force of gravity acting on it. During this "free-fall" the object will increase its velocity by a known rate which Galileo discovered. He discovered that during free-fall, the distance an object falls is proportional to $(\text{time})^2$. Thus, a body will fall 4 times as far during the second #2 than second #1. Additionally, the object's velocity during second #1 = 32.2 ft/s (9.81 m/s), and increases by 32.2 ft/s for each second thereafter.

note! During free-fall, velocity is increasing, not acceleration.

time	distance	Δd	velocity
1s	16 ft	16 ft	32 ft/s
2s	64 ft	48 ft	64 ft/s
3s	144 ft	80 ft	96 ft/s
4s	256 ft	112 ft	128 ft/s
5s	400 ft	144 ft	160 ft/s
6s	576 ft	176 ft	192 ft/s
7s	784 ft	208 ft	224 ft/s

ex.12: Where would object be after 8 seconds of free-fall?

sol: 784 ft + 208 ft + 32 ft = **1,024 ft**

> On earth a body will accelerate downward at a rate of 32.2 ft/s^2 or 9.8 m/s^2 (regardless of it mass).

Terminal velocity is reached when the air resistance force equals the weight force of the falling object, and it no longer accelerates, but rather falls with a constant velocity.

>When a person falls in a "spread" position from a plane they will gain velocity for the first 12 seconds (to ~ 1,483 ft of fall). Afterwards a constant velocity is reached ~118 mi./h (174 ft/s) because the air resistance encountered is equal to the gravitational pull on them. The terminal velocity is decreased as the effective area of the object increases. Thus, the use of a parachute lowers the terminal velocity such that one will hit the ground at a safer speed at around 14 mph (*or* 6.3 m/s) "Why raindrops don't kill." -----> v_f ~ 7 mph

Two thoughts on free-fall;

- Contrary to legend, there is no evidence that Galileo ever dropped a cannon ball and musket ball from the Leaning Tower of Pisa (Campanile). It is possible he was aware of a similar experiments done in 1586 by a Dutch mathematician and engineer Simon Stevin who had experimented by dropping various lead weights from a 10 meter tower and showed the same time of arrival at the ground. These results were published and may have been known to Galileo.
- Sometime in the early 1580's Galileo as a medical student in Pisa noted the falling of different size hail stones from clouds. According to Aristotle's concept of falling bodies, the larger stones would have needed to have formed and fallen from much greater heights within the cloud than the smaller ones. Galileo gave a simpler explanation, that they were made at the same elevation and fell with the same speed.

What is the final velocity of an accelerating object?

- It depends on the magnitude acceleration is and how much time it has been accelerating.

ex.13; What is the final velocity of an object released from rest after 5 seconds of free-fall?

sol; use $a = \Delta v / \Delta t = v_f - v_i / t_2 - t_1$ -----> Being the object started from rest, $v_i = 0$ and drops out.

acceleration (a) = $\Delta v / \Delta t$ and solve for v_f ----> $v_f = a\Delta t = (9.8\ m/s^2)(5\ s) =$ **39.2 m/s**

ex.14; What is the final velocity of a race car that accelerates at 3 m/s^2 from rest after 8 seconds?

sol; use $a = \Delta v / \Delta t = v_f - v_i / t_2 - t_1$ -----> Being the object started from rest, $v_i = 0$ and drops out.

acceleration (a) = $\Delta v / \Delta t$ and solve for v_f ----> $v_f = a\Delta t = (3\ m/s^2)(8\ s) =$ **24 m/s**