

Name: _____

Class: _____

Due Date: _____

A.0 Math

Understandings

- Fundamental and derived SI units
- Scientific notation and metric multipliers
- Significant figures
- Orders of magnitude
- Estimation
- Random and systematic errors
- Absolute, fractional, and percentage uncertainties
- Error bars
- Uncertainty of gradient and intercepts
- Vector and scalar quantities
- Combination and resolution of vectors

If you are interested in learning more about mathematical physics then please read the books *Mathematical Methods in the Physical Sciences* by Mary L. Boas and *div grad curl and all that* by H.M. Schey.

The solutions can be found on the YouTube channel Go Physics Go:

<https://www.youtube.com/@gophysicsgo/playlists>

Part 1: Define the fundamental units

<https://www.nist.gov/pml/weights-and-measures/metric-si/si-units>

Quantity	Unit	Definition
/		

Memorize these two acronyms to memorize the SI fundamental units:

My Knuckles Grow Stronger And Kill More Creatures
=
Meters KiloGrams Seconds Amperes Kelvin Moles Candela

Part 2: Answer the following questions about fundamental units

<https://physics.nist.gov/cuu/Units/units.html>

<https://www.nist.gov/pml/weights-and-measures/metric-si/si-units>

1. What is the meaning and what are the fundamental units of *perimeter*?
2. What is the meaning, equation, and the fundamental units of *circumference*?
3. What is the meaning and what are the fundamental units of *area*?
4. What is the meaning and what are the fundamental units of *volume*?
5. Use the equation $\vec{v} = \frac{\Delta\vec{x}}{\Delta t}$ to solve for the fundamental units of *velocity*.
6. Use the equation $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ to solve for the fundamental units of *acceleration*.
7. Use the equation $\vec{j} = \frac{\Delta\vec{a}}{\Delta t}$ to solve for the fundamental units of *jerk*.
8. What are the units of *force*?

9. Use the equation $\sum \vec{F} = m\vec{a}$ to solve for the fundamental units of *force*.
10. What are the units of *energy*?
11. Use the equation $E_k = \frac{1}{2}mv^2$ to solve for the fundamental units of *kinetic energy*.
12. Use the equation $E_p = m\vec{g}\vec{h}$ to solve for the fundamental units of the *gravitational potential energy* near the surface of a planet.
13. What are the fundamental units of *energy*?
14. What are the units of *work*?
15. Use the equation $W = \vec{F}\vec{d} \cos \theta$ to solve for the fundamental units of *work* W .
16. What is the relationship between the fundamental units of *work* and *energy*?
17. What are the units of *power*?
18. Use the equation $P = \frac{\text{Work}}{t}$ to solve for the fundamental units of *power* P .

19. Use the equation $\vec{p} = m\vec{v}$ to solve for the fundamental units of *momentum* \vec{p} .
20. What are the units of *pressure*?
21. Use the equation $P = \frac{F}{A}$ to solve for the fundamental units of *pressure* P .
22. Use the equation $PV = nRT$ to solve for the fundamental units of the *ideal gas constant* R .
23. What is the meaning and what are the fundamental units of *period* T ?
24. What is the meaning and what are the fundamental units of *frequency* f ?
25. What is the meaning and what are the fundamental units of *wavelength* λ ?
26. Intensity is defined as power per unit area. What are the fundamental units of *intensity* I ?
27. Use the equation $F_{\text{electric}} = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$ to solve for the fundamental units of the *permittivity of free space* ϵ_0 .
28. Use the equation $\vec{F}_e = q\vec{E}_{\text{ext}}$ to solve for the fundamental units of the *electric field* E .

29. What are the units of *current* I ? Use the equation $I = \frac{\Delta q}{\Delta t}$ to solve for the fundamental units of *current* I .
30. Use the equation $I = \frac{\Delta q}{\Delta t}$ to solve for the fundamental units of *charge* q .
31. Use the equation $V = W/q$ to solve for the fundamental units of *voltage* V .
32. What are the units for the *resistance* in a resistor R ?
33. Use the equation $V = IR$ to solve for the fundamental units of *resistance* R .
34. What are the units of *magnetic field* \vec{B} ?
35. Use the equation $\vec{F}_B = q\vec{v}\vec{B}_{\text{ext}}$ to solve for the fundamental units of the *magnetic field* \vec{B} .
36. Use the equation $F_{\text{gravity}} = \frac{Gm_1m_2}{r^2}$ to solve for the fundamental units of the *gravitational constant* G .
37. Use the equation $E = hf$ to solve for the fundamental units of *Planck's constant* h .
38. Use the equation $P = e\sigma AT^4$ to solve for the fundamental units of the *Stefan-Boltzmann constant* σ . The variable e is unitless.

Part 3: Determine the number of significant figures

1. 1,000	21.0.00020	41.100.00
2. 1,000.	22.0.0205	42.300.0000
3. 1,000.00	23.0.2	43.301
4. 1,020	24.8,000	44.301.001
5. 1020.	25.8,070	45.301.0010000
6. 1,020.0	26.8.0	46.8,670
7. 1,000.001	27.8.007	47.80,600
8. 1,200	28.800,700	48.8,670.00
9. 1,200.	29.800,700.00	49.1,000,000
10.1,200.00	30.4	50.1,200,000
11.1,200.03	31.4.0	51.1,205,000
12.1,200.0300	32.4.000	52.4,000
13.100200	33.1.2	53.4,300
14.100200.	34.1.25	54.4,300.
15.100200.00	35.1.250000	55.4,030
16.4,500	36.10	56.4003
17.4,050	37.10.	57.4,003.
18.405	38.100	
19.0.0000405	39.101	
20.0.0002	40.100.	

5. The circumference of the Earth is about 40,075.017 km from the Equator. What is the circumference of the Earth in inches? Show all your work and place a box around your answer.

6. The surface area of Earth is about 510,064,472 square kilometers. What is the surface area of the Earth in square inches? Show all your work and place a box around your answer.

7. The volume of Earth is about 1,083,206,916,846 cubic kilometers. What is the volume of Earth in cubic inches? Show all your work and place a box around your answer.

8. The speed of light is 299,792,458 m/s. What is the distance, in kilometers, light travels in one year? Show all your work and place a box around your answer.

9. The density of gold is 19.32 grams per cubic centimeters. What is the density of gold in kilograms per cubic meters? Show all your work and place a box around your answer.

10. The density of gold is 19.32 grams per cubic centimeters. What is the density of gold in pounds per cubic feet? Show all your work and place a box around your answer.

11. A man drinks 60 liters of water in a 30 day month. On average how many cubic meters of water does he drink per hour? Show all your work and place a box around your answer.

Part 5: Answer the following questions

1. Define *random error* and give two examples.
2. Define *systematic error* and give two examples.
3. Define *accuracy* and give an example of high accuracy and low accuracy.
4. Define *precision* and give an example of high precision and low precision.
5. List some rules with regards to uncertainties in measurements.

Part 6: Learn how to add, subtract, multiply, and divide uncertainties

$$1. \quad \begin{array}{r} 3.14 \pm 0.15 \\ + \quad 9.26 \pm 0.53 \end{array}$$

$$2. \quad \begin{array}{r} 6.26 \pm 0.43 \\ + \quad 3.8 \pm 0.27 \end{array}$$

$$3. \quad \begin{array}{r} 1.69 \pm 0.39 \\ + \quad 9.37 \pm 0.51 \end{array}$$

$$4. \quad \begin{array}{r} 5.89 \pm 0.79 \\ - \quad 3.23 \pm 0.84 \end{array}$$

$$5. \quad \begin{array}{r} 9.50 \pm 0.28 \\ - \quad 8.4 \pm 0.97 \end{array}$$

$$6. \quad \begin{array}{r} 5.82 \pm 0.09 \\ - \quad 4.94 \pm 0.45 \end{array}$$

$$7. \quad \begin{array}{l} 3.14 \pm 0.15 \\ \times \quad 9.26 \pm 0.53 \end{array}$$

$$8. \quad \begin{array}{l} 6.26 \pm 0.43 \\ \times \quad 3.8 \pm 0.27 \end{array}$$

$$9. \quad \begin{array}{l} 1.69 \pm 0.39 \\ \times \quad 9.37 \pm 0.51 \end{array}$$

$$10. \quad \begin{array}{r} 5.89 \pm 0.79 \\ \div \quad 3.23 \pm 0.84 \end{array}$$

$$11. \quad \begin{array}{r} 9.50 \pm 0.28 \\ \div \quad 8.4 \pm 0.97 \end{array}$$

$$12. \quad \begin{array}{r} 5.82 \pm 0.09 \\ \div \quad 4.94 \pm 0.45 \end{array}$$

13. $(3.14 \pm 0.15)^2$

14. $(9.26 \pm 0.53)^3$

15. $(6.26 \pm 0.43)^4$

16. $\sqrt{(3.14 \pm 0.15)}$

17. $\sqrt[3]{(9.26 \pm 0.53)}$

18. $\sqrt[4]{(6.26 \pm 0.43)}$

19. What is the percent uncertainty of the perimeter of a rectangle if has a length of 2.45 ± 0.3 m and a width of 3.56 ± 0.4 m?

20. What is the percent uncertainty of the area of a rectangle if its length is uncertain by 3% and its width is uncertain by 4%?

21. What is the percent uncertainty of the volume of a box if its length is uncertain by 3%, its width is uncertain by 4%, and its height is uncertain by 5%?

22. What is the percent uncertainty of the perimeter/circumference of a circle if its radius is uncertain by 7%?

23. What is the percent uncertainty of the area of a circle if its radius is uncertain by 7%?

24. What is the percent uncertainty of the volume of a sphere if its radius is uncertain by 7%?

25. Mustafa has a height of (172 ± 0.2) cm. Nour has a height of (167 ± 0.35) cm. How much taller, including uncertainty, is Mustafa taller than Nour?

26. Twelve identical square tiles each have a length of 45.62 cm with an uncertainty of 0.2 cm. What is the total length, including uncertainty, of the 12 tiles if they are each placed side-by-side?

27. What is the perimeter, including uncertainty, of a rectangle with a length of (3.14 ± 0.15) cm and a width of (9.26 ± 0.53) cm?

28. What is the area, including uncertainty, of a rectangle with a length of (3.14 ± 0.15) cm and a width of (9.26 ± 0.53) cm?

29. What is the volume, including uncertainty, of a box with a length of (3.14 ± 0.15) cm, a width of (9.26 ± 0.53) cm, and a height of (6.26 ± 0.43) cm?

30. What is the perimeter/circumference, including uncertainty, of a circle with a radius of (3.83 ± 0.27) cm?

31. What is the area, including uncertainty, of a circle with radius of (3.83 ± 0.27) cm?

32. What is the volume, including uncertainty, of a sphere with radius of (3.83 ± 0.27) cm?

33. What is the speed, including uncertainty, of a boat which travels (31.41 ± 0.59) m in (2.65 ± 0.35) s?

Part 7: Define the following terms

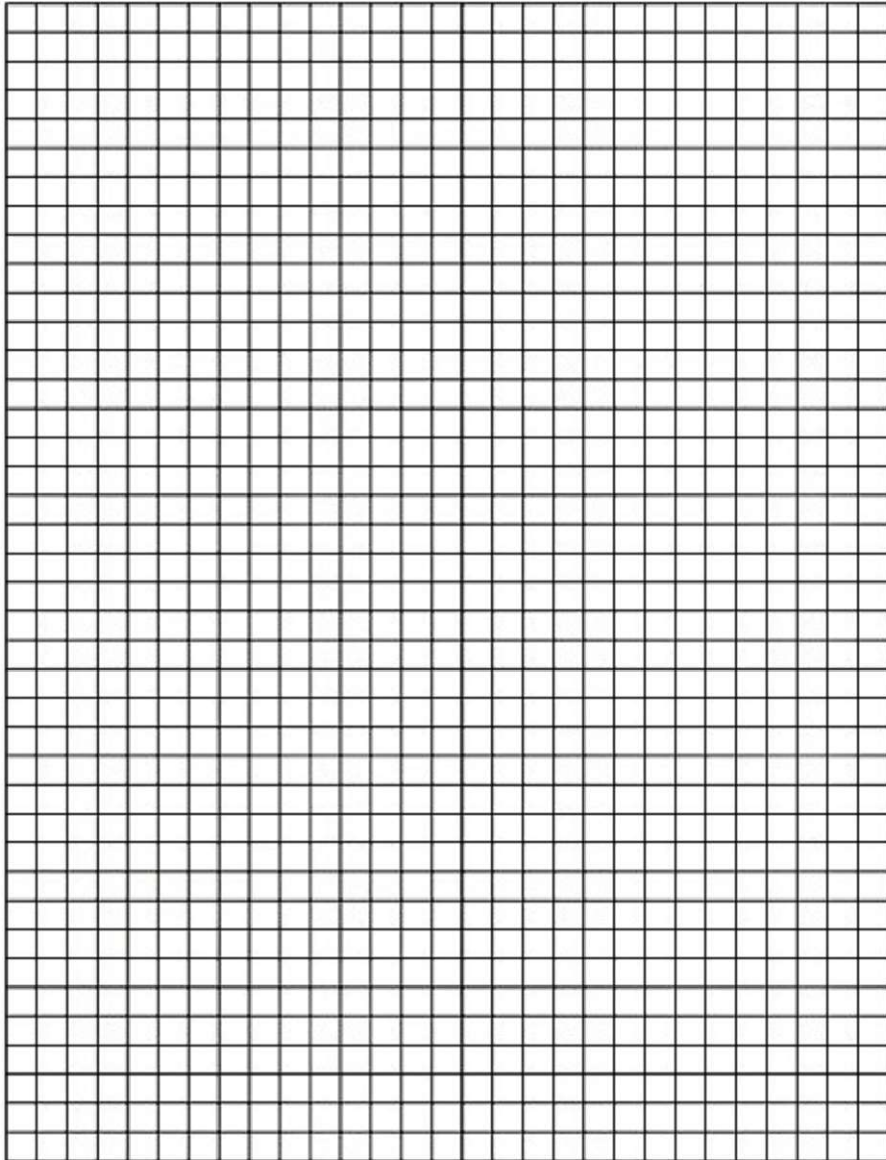
1. magnitude
2. scalar
3. vector (What is the symbol for a vector?)

Part 8: Determine if the following quantities are *scalars* or *vectors*.

1. Money	23. Impulse
2. Perimeter	24. Pressure
3. Circumference	25. Moles
4. Area	26. Temperature
5. Volume	27. Wavelength
6. Angle	28. Period
7. Time	29. Frequency
8. Length	30. Charge
9. Distance	31. Current
10. Displacement	32. Voltage
11. Speed	33. Gravitational field strength
12. Velocity	34. Energy density
13. Acceleration	35. Specific energy
14. Jerk	36. Angular speed
15. Force	37. Angular acceleration
16. Work	38. Electric Potential
17. Calories	39. Electric field
18. Energy	40. Magnetic field
19. Kinetic energy	41. Electromotive force
20. Potential energy	42. Moment of inertia
21. Power	43. Entropy
22. Momentum	44. Reynold's number

Part 9: Drawing vectors. Use a pencil and ruler!

1. Let the vectors $\vec{A} = (x_1, y_1) = (3, -2)$ and $\vec{B} = (x_2, y_2) = (-1, 4)$
 - a. Draw a horizontal and vertical axis on the graph on the next page. Label the horizontal axis x and the vertical axis y .
 - b. Draw \vec{A} on the graph below.
 - c. What is the magnitude of the horizontal component of \vec{A} ?
 - d. What is the magnitude of the vertical component of \vec{A} ?
 - e. What is the magnitude of \vec{A} ?
 - f. Draw \vec{B} on the graph below.
 - g. What is $\vec{A} + \vec{B}$? Draw it on the graph below.
 - h. What is the magnitude of the horizontal component of $\vec{A} + \vec{B}$?
 - i. What is the magnitude of the vertical component of $\vec{A} + \vec{B}$?
 - j. What is the magnitude of $\vec{A} + \vec{B}$?
 - k. What is $\vec{B} + \vec{A}$? Draw it on the graph below.
 - l. What is $\vec{A} - \vec{B}$? Draw it on the graph below.
 - m. What is $\vec{B} - \vec{A}$? Draw it on the graph below.
 - n. What is $-\vec{A} - \vec{B}$? Draw it on the graph below.
 - o. What is $-\vec{B} - \vec{A}$? Draw it on the graph below.



Part 10: The Classic “Boat Crossing a River” Problem

1. Adam is on a boat. It is moving from south to north on a river at a speed of 9 m/s. The water in the river is moving from east to west with a speed of 4 m/s. The river is 81 m wide.
 - a. Draw a figure.
 - b. How long will it take for the boat to reach the other side?
 - c. How many meters will the boat have traveled westward?
 - d. What will be the total displacement of the boat?

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A.1 Kinematics

Understandings

- The motion of bodies through space and time can be described and analyzed in terms of position, velocity, and acceleration.
- The velocity is the rate of change of position and acceleration is the rate of change of velocity.
- The change in position is the displacement.
- The difference between distance and displacement.
- The difference between the instantaneous and average values of velocity, speed, and acceleration, and how to describe them.
- The equations of motion for solving problems with uniformly accelerated motion as given by
 - $s = \frac{u+v}{2}t$
 - $v = u + at$
 - $s = ut + \frac{1}{2}at^2$
 - $v^2 = u^2 + 2as$
- Motion with uniform and non-uniform acceleration.
- The behavior of projectiles in the absence of fluid resistance, and the application of the equations of motion resolved into vertical and horizontal components.
- The qualitative effect of fluid resistance on projectiles, including time of flight, trajectory, velocity, acceleration, range, and terminal speed.

Equations

$$s = \frac{u+v}{2} t$$

$$v = u + at$$

$$s = ut + \frac{1}{2} at^2$$

$$v^2 = u^2 + 2as$$

Interesting facts

- The record for the tallest person in the world is Robert Wadlow who measured 272 cm. He died at the age of 22.
- The record for the tallest building in the world is the Burj Khalifa in the United Arab Emirates which is almost 830 m tall.
- The record for the tallest mountain above sea level is Mount Everest which is located between China and Nepal. It is measured to be about 8,848 m above sea level.
- The record for the lowest depth below sea level is the Mariana Trench which is about 10,984 m below sea level. Surprisingly both life and pollution is found near the bottom of the Marina Trench.
- The fastest baseball pitch ever recorded is from Aroldis Chapman at which was about 169.1 km/h or 46.97 m/s.

Super Ultimate Graphing Challenge

<http://theuniverseandmore.com/>

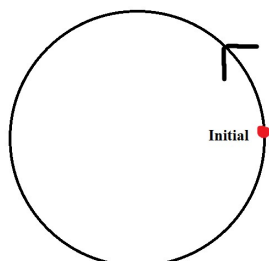
The solutions can be found on the YouTube channel Go Physics Go:

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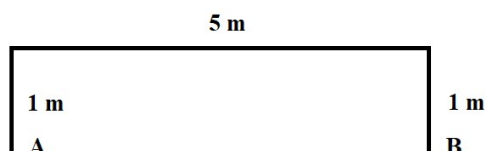
Part 1: Use your favorite sources to answer the following questions

1. What is the meaning of zero dimensions? One dimension? Two dimensions? Three dimensions? Four dimensions? If possible draw a figure for each.
2. Define *position*.
3. Define *distance*. Scalar or vector? Units? Example? Can *distance* be negative?
4. Define *displacement*. Scalar or vector? Units? Example? Can *displacement* be negative?
5. Define *speed*. Scalar or vector? Equation? Units? Example? Can *speed* be negative?
6. Define *velocity*. Equation? Units? Example? Can *velocity* be negative?
7. Define *average speed*. Scalar or vector? Equation? Units?
8. Define *average velocity*. Scalar or vector? Equation? Units?

9. An object moves in a circle with a radius of 3 m. It takes the object 4 seconds to complete one revolution.



- a. What is the average speed and the average velocity of the object after it completes **one** cycle/revolution?
- b. What is the average speed and the average velocity of the object after it completes **one-half** cycle/revolution?
10. An object starts from rest at point A and then travels to point B by moving north 1 m, then east 5 m, and finally south 1 m in a total time of 14 seconds. What is the average speed and the average velocity of the object when it moves from point A to point B?



11. Define *instantaneous speed*. Example?

12. Define *instantaneous velocity*. Example?

13. Define *acceleration*. Equation? Units? Example? Can *acceleration* be negative?

14. What is the magnitude of the acceleration of free fall \vec{g} near the surface of the Earth? Which direction/way does it point? Is it positive or negative?

15. Define *projectile motion*.

16. What does the slope of a *displacement vs. time* graph tell us? Equation? Units?

17. What does the slope of a *velocity vs. time* graph tell us? Equation? Units?

18. What does the slope of an *acceleration vs. time* graph tell us? Equation? Units?

19. What does the area under a *displacement vs. time* graph tell us? Units?

20. What does the area under a *velocity vs. time* graph tell us? Units?

21. What does the area under an *acceleration vs. time* graph tell us? Units?

22. How would you go about determining the acceleration due to gravity near the surface of the Earth? Which equation will you use? Which instruments do you need? What will you do?

23. **Use a pencil and ruler!** Define *terminal velocity*. What is the relationship between speed and the force of friction? Draw a *distance vs. time* graph, a *speed vs. time* graph, and an *acceleration vs. time* graph of an object being dropped from rest from a very high height above the surface of the Earth with both the force of friction and the force of gravity acting on it.

24. **Use a pencil and ruler!** Draw a *speed vs. time* graph of a skydiver first jumping out of an airplane, then reaching terminal velocity, then opening his parachute, then reaching a second terminal velocity, and finally hitting the ground.

25. A ball/projectile is thrown with an initial angle of 50 degrees. Draw its trajectory with no air friction and with air friction.

26. A ball is thrown vertically upwards with an initial velocity of 40 m/s in the absence of air friction. For this problem let the acceleration due to gravity be 10 m/s^2 down.

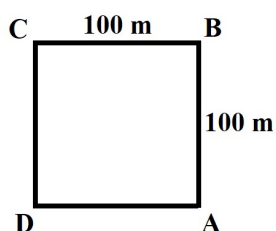
a. Fill out the table below:

Time (s)	Acceleration $\left[\frac{\text{m}}{\text{s}^2}\right]$	Velocity $\left[\frac{\text{m}}{\text{s}}\right]$ $v_f = at + v_i$	Displacement [m] $y_f = \frac{1}{2}at^2 + v_i t + y_i$	Total distance traveled [m]
0				
1				
2				
3				
4				
5				
6				
7				
8				

- b. **Use a pencil and ruler!** Draw an *acceleration vs. time* graph, a *velocity vs. time* graph, a *speed vs. time* graph, a *displacement vs. time* graph, and a *distance vs. time* graph for the ball.

Part 2: Distance Displacement Speed Velocity

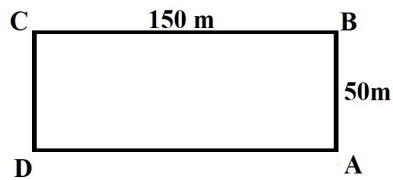
1. Wayde Van Niekerk from Russia runs 400 meters at a constant speed around a square track in a time of 43.03 seconds beginning at point A in a counterclockwise direction as shown below.



Complete the following table by determining the distance, displacement, speed, and velocity of Wayde Van Kiekerk at the following points. State both the magnitude and direction for the displacement and velocity of Wayde Van Kiekerk.

	Point B	Point C	Point D	Point A
Total Distance				
Total Displacement				
Average Speed				
Average Velocity				

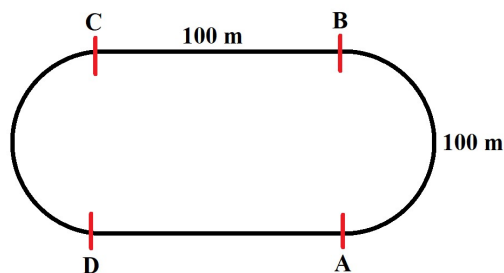
2. Wayde Van Niekerk from Russia runs 400 meters at a constant speed around a rectangular track in a time of 43.03 seconds beginning at point A in a counterclockwise direction as shown below.



Complete the following table by determining the distance, displacement, speed, and velocity of Wayde Van Kiekerk at the following points. State both the magnitude and direction for the displacement and velocity of Wayde Van Kiekerk.

	Point B	Point C	Point D	Point A
Total Distance				
Total Displacement				
Average Speed				
Average Velocity				

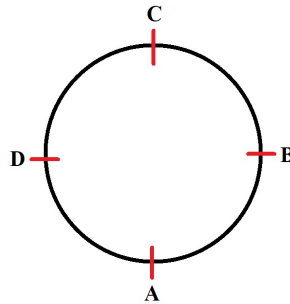
3. Wayde Van Niekerk from Russia runs 400 meters at a constant speed around an Olympic track in a time of 43.03 seconds beginning at point A in a counterclockwise direction as shown below. Each semicircle has a length of 100 meters.



Complete the following table by determining the distance, displacement, speed, and velocity of Wayde Van Kiekerk at the following points. State both the magnitude and direction for the displacement and velocity of Wayde Van Kiekerk.

	Point B	Point C	Point D	Point A
Total Distance				
Total Displacement				
Average Speed				
Average Velocity				

4. Wayde Van Niekerk from Russia runs 400 meters at a constant speed around a circular track in a time of 43.03 seconds beginning at point A in a counterclockwise direction as shown below.

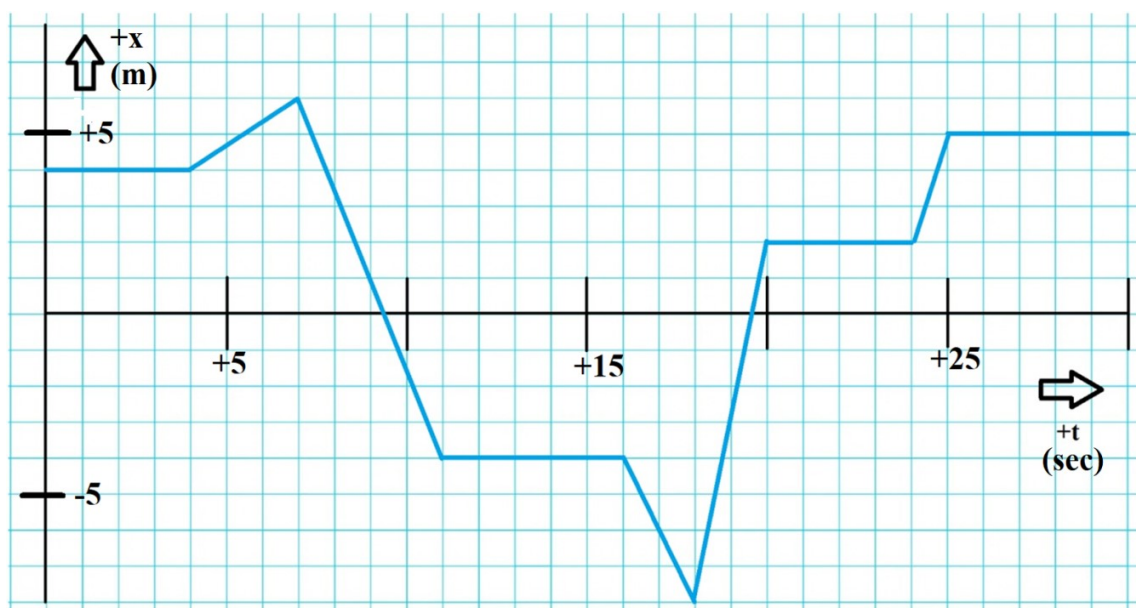


Complete the following table by determining the distance, displacement, speed, and velocity of Wayde Van Kiekerk at the following points. State both the magnitude and direction for the displacement and velocity of Wayde Van Kiekerk.

	Point B	Point C	Point D	Point A
Total Distance				
Total Displacement				
Average Speed				
Average Velocity				

Part 3: Motion graphs

1. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *displacement vs. time* graph is shown below.

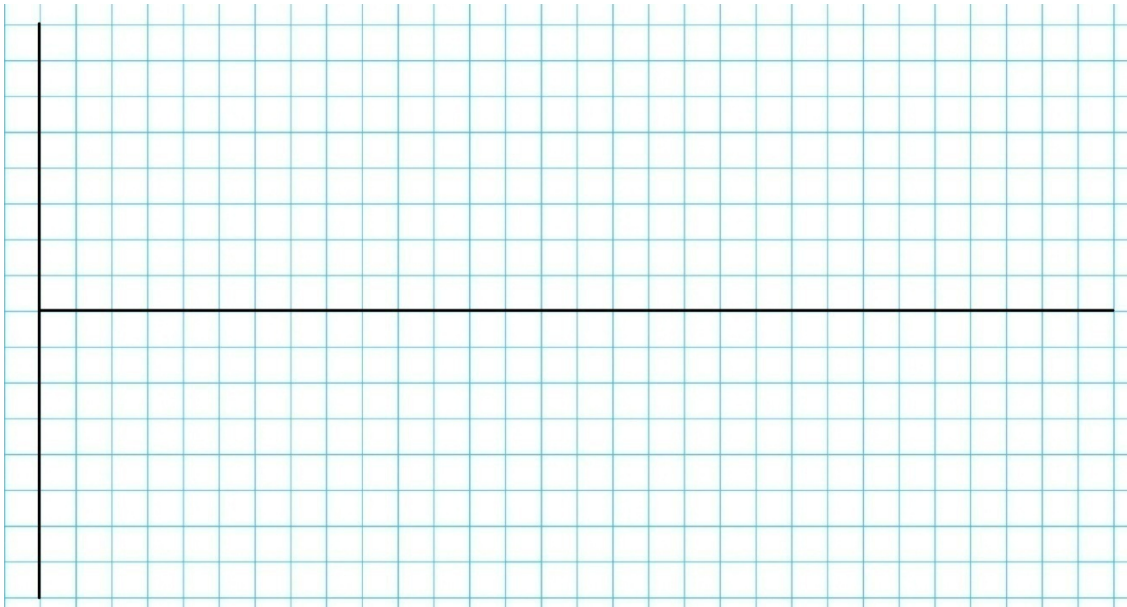


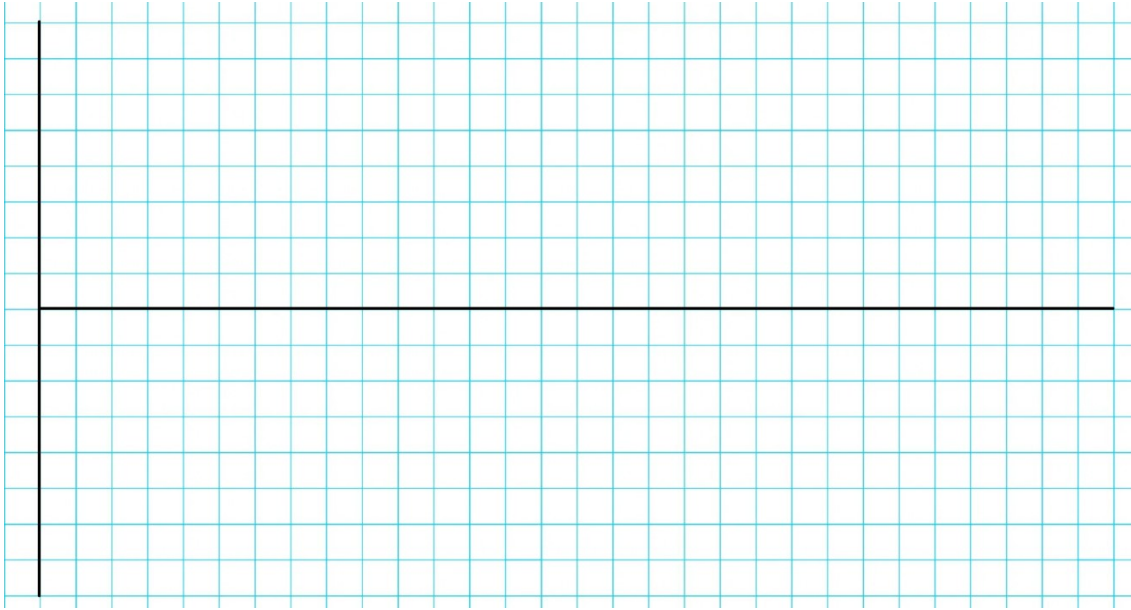
a. What does the slope of a *displacement vs. time* graph tell us?

b. Determine the *displacement* and *velocity* of the object at

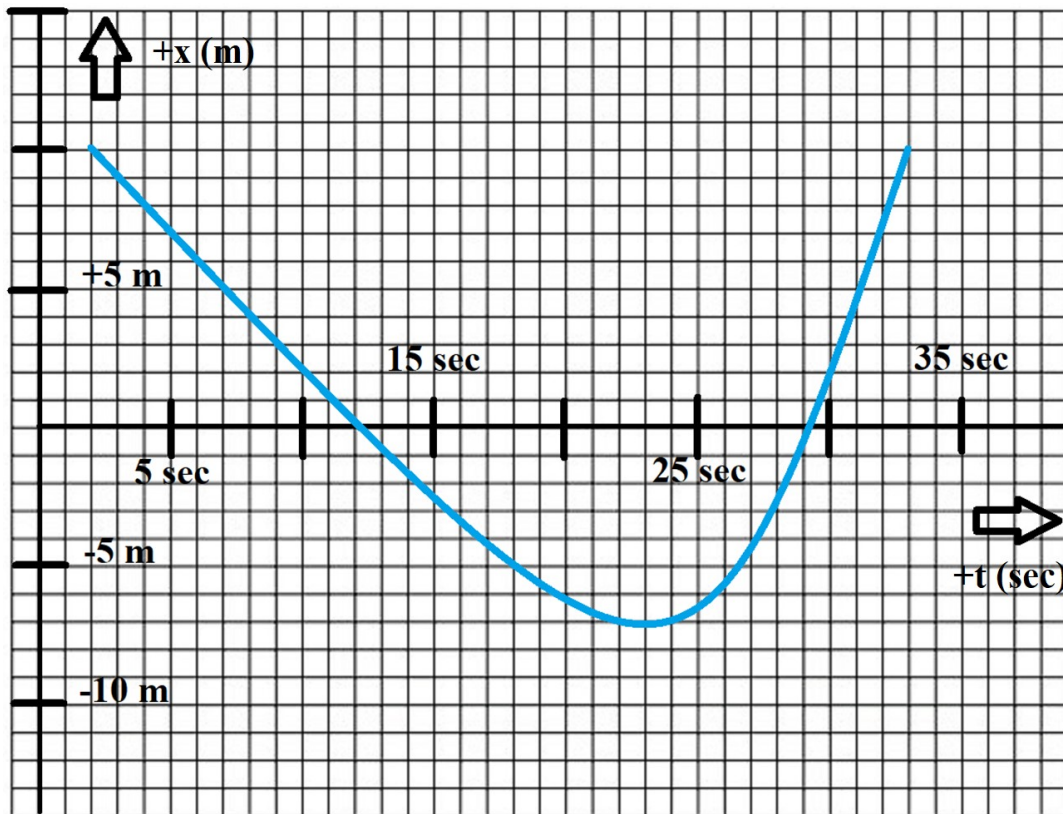
- i. $t = 3$ s
- ii. $t = 5$ s
- iii. $t = 9$ s
- iv. $t = 13$ s
- v. $t = 17$ s
- vi. $t = 19$ s
- vii. $t = 23$ s
- viii. $t = 24.5$ s
- ix. $t = 28$ s

- c. What is the *total distance* the object travels from $t = 0$ s to $t = 30$ s?
- d. What is the *displacement* of the object from $t = 0$ s to $t = 30$ s?
- e. What does the slope of a *velocity vs. time* graph tell us?
- f. **Use a pencil and ruler!** On the graphs below draw a *velocity vs. time* graph and an *acceleration vs. time* graph. Label your axes!





2. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *displacement vs. time* graph is shown below.



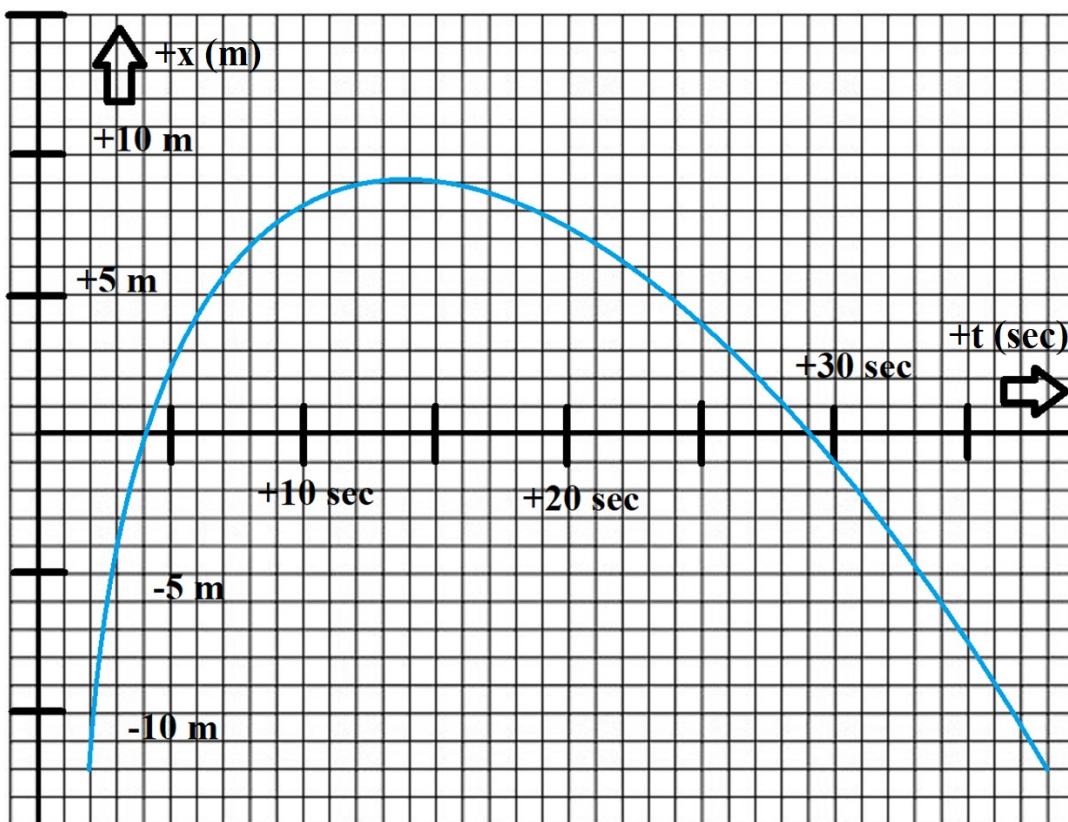
- a. Is the object moving to the left or the right? Is it speeding up or slowing down?
 - i. From $t = 2 \text{ s}$ to $t = 12 \text{ s}$
 - ii. From $t = 12 \text{ s}$ to $t = 23 \text{ s}$
 - iii. From $t = 23 \text{ s}$ to $t = 29 \text{ s}$
 - iv. From $t = 29 \text{ s}$ to $t = 33 \text{ s}$

- b. Determine the *displacement* and *velocity* of the object at
 - i. $t = 12 \text{ s}$
 - ii. $t = 23 \text{ s}$
 - iii. $t = 29 \text{ s}$

c. What is the *total distance* the object travels from $t = 2$ s to $t = 33$ s?

d. What is the *displacement* of the object from $t = 2$ s to $t = 33$ s?

3. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *displacement vs. time* graph is shown below.



a. Is the object moving to the left or the right? Is it speeding up or slowing down?

- i. From $t = 2$ s to $t = 4$ s
- ii. From $t = 4$ s to $t = 14$ s
- iii. From $t = 14$ s to $t = 29$ s
- iv. From $t = 29$ s to $t = 38$ s

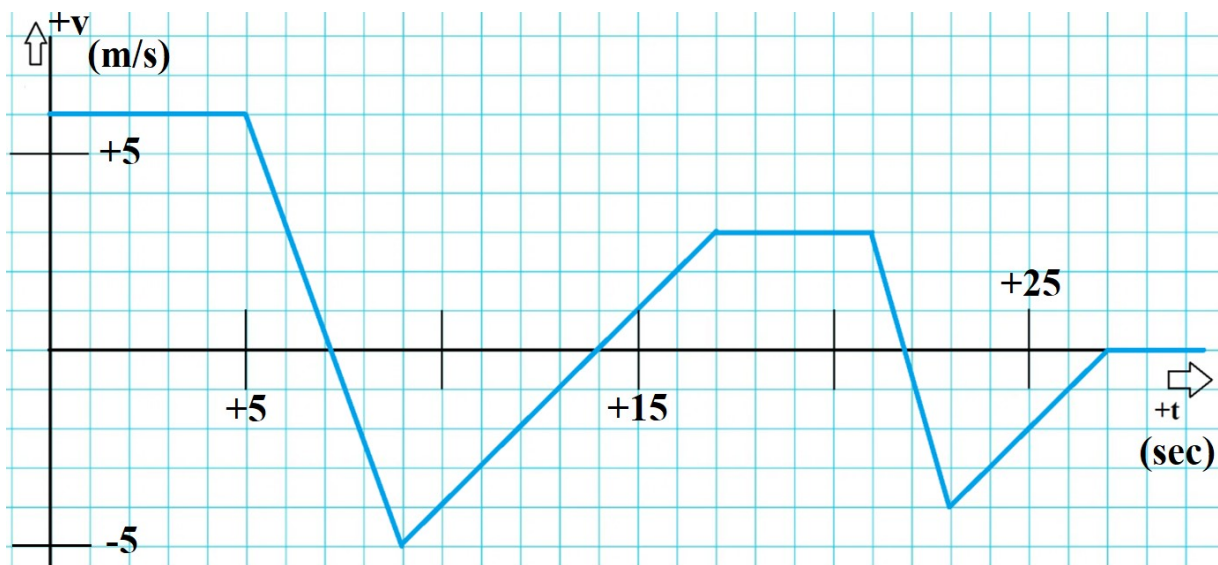
b. Determine the *displacement* and *velocity* of the object at

- i. $t = 4 \text{ s}$
- ii. $t = 14 \text{ s}$
- iii. $t = 29 \text{ s}$

c. What is the *total distance* the object travels from $t = 2 \text{ s}$ to $t = 38 \text{ s}$?

d. What is the *displacement* of the object from $t = 2 \text{ s}$ to $t = 38 \text{ s}$?

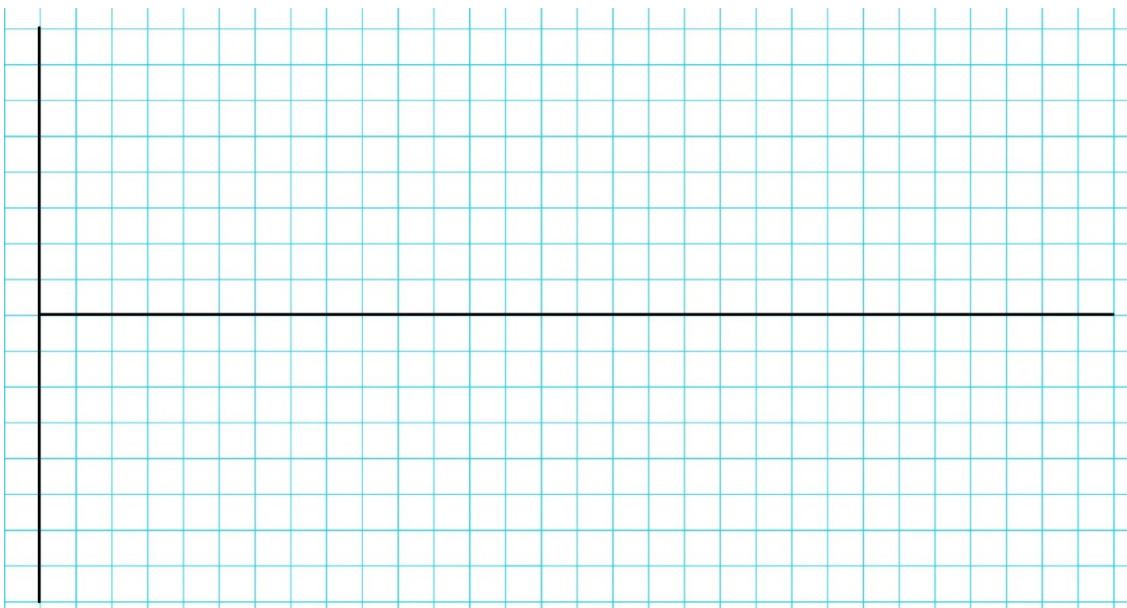
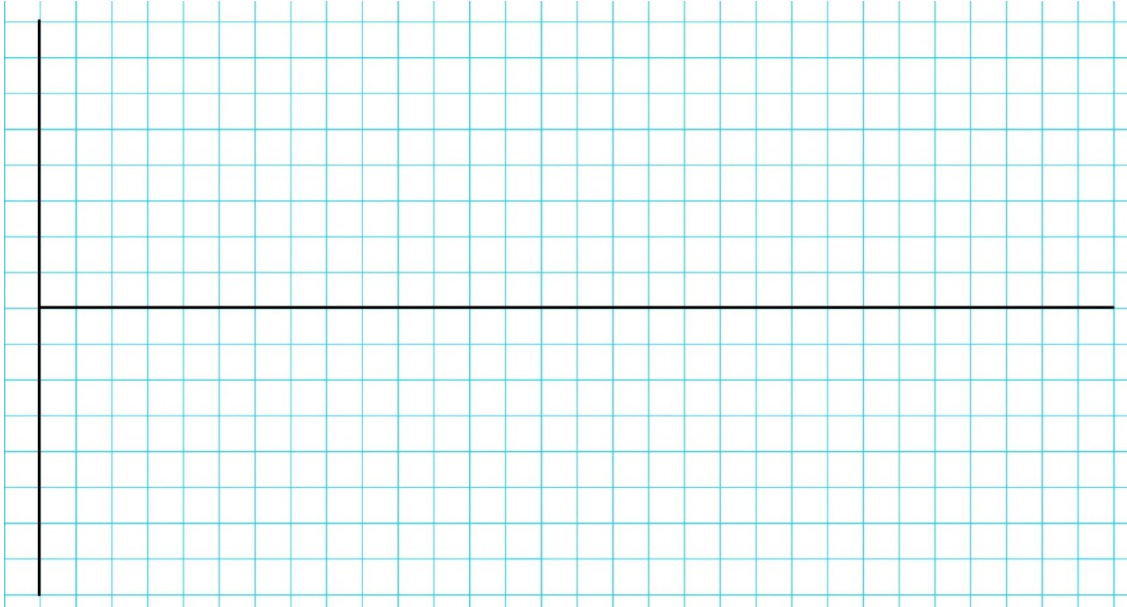
4. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *velocity vs. time* graph is shown below.



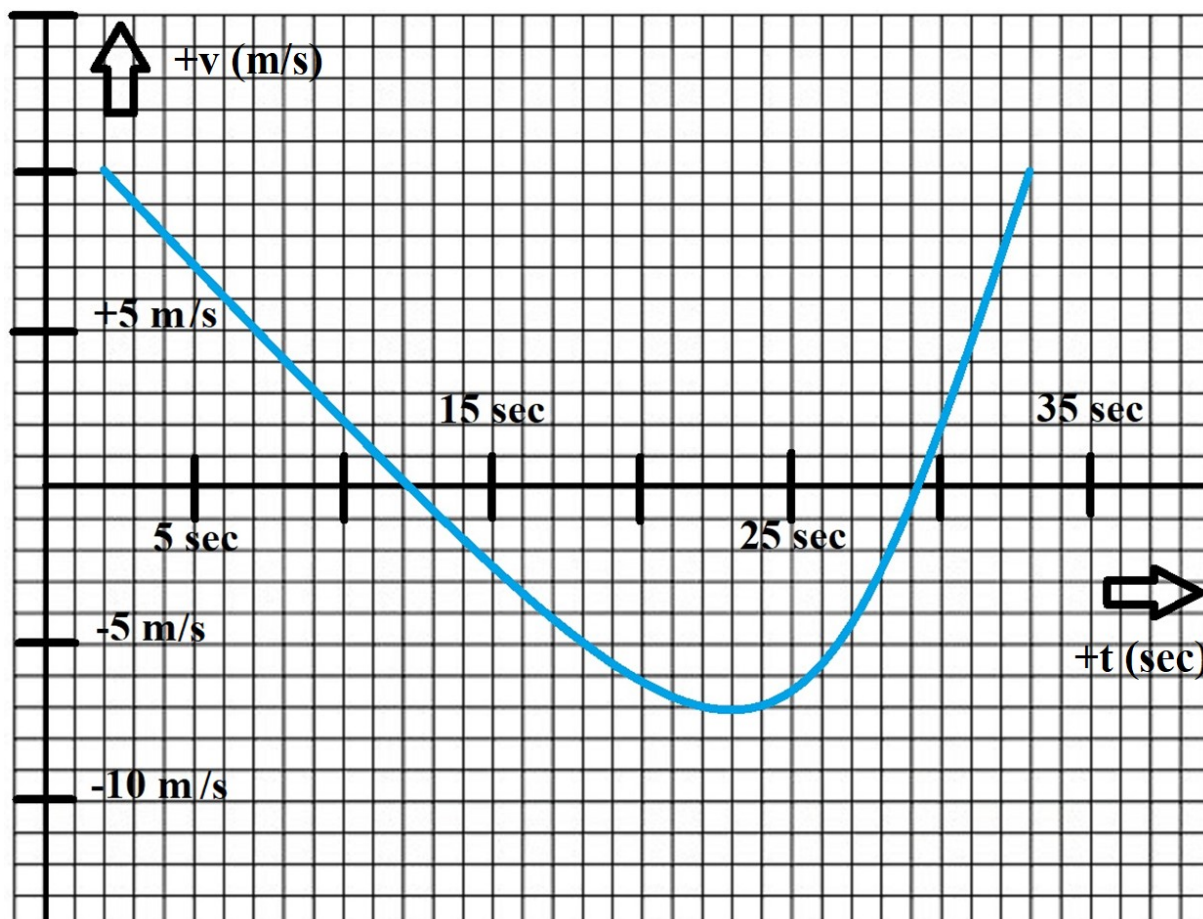
a. What does the slope of a *velocity vs. time* graph tell us?

- b. Find the *velocity* and the *acceleration* of the object at
- i. $t = 3 \text{ s}$
 - ii. $t = 7 \text{ s}$
 - iii. $t = 8 \text{ s}$
 - iv. $t = 10 \text{ s}$
 - v. $t = 14 \text{ s}$
 - vi. $t = 18 \text{ s}$
 - vii. $t = 22 \text{ s}$
 - viii. $t = 29 \text{ s}$
- c. What does the area under a *velocity vs. time* graph tell us?
- d. Find the *displacement* of the object from
- i. $t = 0 \text{ s}$ to $t = 5 \text{ s}$
 - ii. $t = 5 \text{ s}$ to $t = 9 \text{ s}$
 - iii. $t = 9 \text{ s}$ to $t = 17 \text{ s}$
 - iv. $t = 17 \text{ s}$ to $t = 27 \text{ s}$
- e. Determine the *total distance* the object travels from $t = 0 \text{ s}$ to $t = 29 \text{ s}$.
- f. Determine the *displacement* of the object from $t = 0 \text{ s}$ to $t = 29 \text{ s}$.

- g. Use a pencil and ruler! On the graphs below draw an *acceleration vs. time* graph and a *displacement vs. time* graph. Label your axes!



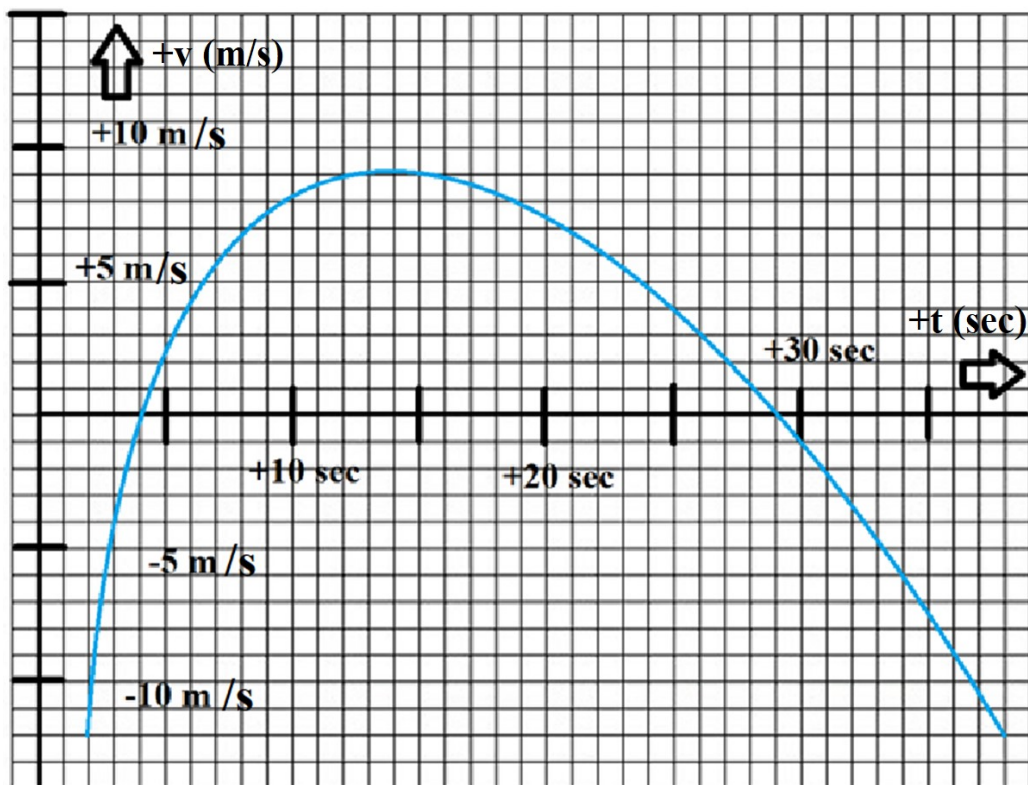
5. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *velocity vs. time* graph is shown below.



- a. Is the object moving to the left or the right? Is its acceleration increasing, decreasing, or constant?
- From $t = 2 \text{ s}$ to $t = 12 \text{ s}$
 - From $t = 12 \text{ s}$ to $t = 23 \text{ s}$
 - From $t = 23 \text{ s}$ to $t = 29 \text{ s}$
 - From $t = 29 \text{ s}$ to $t = 33 \text{ s}$

- b. Determine the *velocity* and *acceleration* of the object at
- $t = 12$ s
 - $t = 23$ s
 - $t = 29$ s
- c. Determine the *total distance* the object travels from $t = 2$ s to $t = 33$ s.
- d. Determine the *displacement* of the object from $t = 2$ s to $t = 33$ s.

6. An object can move to the left or right in one dimension. Positive displacement is towards the right and negative displacement is towards the left. Its *velocity vs. time* graph is shown below.



- a. Is the object moving to the left or the right? Is its acceleration increasing, decreasing, or constant?
- From $t = 2$ s to $t = 4$ s
 - From $t = 4$ s to $t = 14$ s
 - From $t = 14$ s to $t = 29$ s
 - From $t = 29$ s to $t = 38$ s
- b. Determine the *velocity* and *acceleration* of the object at
- $t = 4$ s
 - $t = 14$ s
 - $t = 29$ s
- c. Determine the *total distance* the object travels from $t = 2$ s to $t = 38$ s.
- d. Determine the *displacement* of the object from $t = 2$ s to $t = 38$ s.

- f. What is the total distance the car travels since it started from rest?

- g. What is the total time taken for the car to travel since it started from rest until it reaches a speed of 15 m/s?

- h. Draw a *displacement vs. time* graph, a *velocity vs. time* graph, and an *acceleration vs. time* graph for the car.

2. A car starts from rest and accelerates at a constant rate of 4 m/s^2 for 8 seconds.
- What is the speed of the car after 8 seconds?

- How much distance did the car travel during these 8 seconds?

The car then moves at a constant speed for 12 seconds.

- How much distance did the car travel during these 12 seconds?

The car then slows to a stop at a rate of 3 m/s^2 .

- How much time did it take for the car to decelerate and stop?

- How much distance did the car travel when it decelerates?

- What is the total time taken for the car to travel?

- What is the total distance taken for the car to travel?

- h. Draw a *displacement vs. time* graph, a *velocity vs. time* graph, and an *acceleration vs. time* graph for the car.

3. Enoch throws a ball vertically upwards with an initial speed of 47 m/s at an elevation of 8,848 m above the surface of the Earth.
- a. What will be the acceleration of the ball (number and direction) at the moment after it is thrown upwards?
 - b. What will be the acceleration of the ball (number and direction) when it reaches its maximum height?
 - c. What will be the velocity of the ball when it reaches its maximum height?
 - d. How long will it take for the ball to reach its maximum height?
 - e. How many meters above the surface of the Earth will the ball be when it reaches its maximum height?
 - f. What will be the acceleration of the ball (number and direction) just before it strikes the surface of the Earth?
 - g. What will be the velocity of the ball when it is 8,950 m above the surface of the Earth?
 - h. How long will it take for the ball to be 8,950 m above the surface of the Earth?

- i. What will be the velocity of the ball just before it strikes the ground?

- j. What is the total distance the ball travels during the first 4.5 s?

- k. What is the total distance the ball travels?

- l. How long will it take for the ball to be 300 m above the surface of the Earth?

- m. Draw a displacement vs. time graph, a velocity vs. time graph, and an acceleration vs. time graph for the ball.

4. Noah drops a ball from rest at an elevation 830 m above the surface of the Earth.
- a. What will be the acceleration of the ball (number and direction) at the moment it is dropped?
 - b. What will be the acceleration of the ball (number and direction) when it is 415 m above the surface of the Earth?
 - c. What will be the acceleration of the ball (number and direction) just before it strikes the surface of the Earth?
 - d. How long will it take for the ball to be 415 m above the surface of the Earth?
 - e. What will be the velocity of the ball 415 m above the surface of the Earth?
 - f. What will be the velocity of the ball just before it strikes the ground?
 - g. What is the total distance the ball travels during the first 8 s?

5. Eber throws a ball vertically downwards with an initial speed of 22 m/s from a height of 8,848 m above the surface of the Earth.
- What will be the acceleration of the ball (number and direction) at the moment after it is thrown downwards?
 - What will be the acceleration of the ball (number and direction) just before it strikes the surface of the Earth?
 - What will be the velocity of the ball just before it strikes the surface of the Earth?
 - How long will it take for the ball to reach the surface of the Earth?
 - What will be the velocity of the ball when it is 4,000 m above the surface of the Earth?
 - How long will it take for the ball to reach 4,000 m above the surface of the Earth?
 - What is the total distance the ball travels after 12.5 s?

- h. Draw a displacement vs. time graph, a velocity vs. time graph, and an acceleration vs. time graph for the ball.

6. Salah throws a ball with an initial speed of 47 m/s at an angle of 30° north of east 830 meters above the surface of the Earth.

a. Complete the table:

$x_i =$	$y_i =$
$v_{i,x} =$	$v_{i,y} =$
$a_x =$	$a_y =$

b. What will be the horizontal velocity and horizontal acceleration of the ball (number and direction) when it reaches its maximum height?

c. What will be the vertical velocity and vertical acceleration of the ball (number and direction) when it reaches its maximum height?

d. How long will the ball be in the air for?

e. What will be the range (horizontal distance) of the ball?

f. What will be the maximum height of the ball from the surface of the Earth after it is thrown?

g. How long will it take for the ball to reach its maximum height after it is thrown?

1. What will be the displacement of the ball (number and direction) eight seconds after it is thrown?

- m. Draw an acceleration vs. time graph, a velocity vs. time graph, a speed vs. time graph, a displacement vs. time graph, and a distance vs. time graph for the ball for both the horizontal direction and the vertical direction.

7. Abraham throws a ball horizontally eastward with an initial speed of 22 m/s from 830 meters above the surface of the Earth.
- a. Complete the table:

$x_i =$	$y_i =$
$v_{i,x} =$	$v_{i,y} =$
$a_x =$	$a_y =$

- b. How long will the ball be in the air for after it is thrown?
- c. What will be the range of the ball?
- d. How long does it take for the ball to reach 400 m above the surface of the Earth after it is thrown?
- e. How high above the surface of the Earth will the ball be eight seconds after it is thrown?
- f. How far horizontally does the ball travel during the first eight seconds after it is thrown?

g. What will be the velocity of the ball (number and direction) eight seconds after it is thrown?

h. What will be the displacement of the ball (number and direction) eight seconds after it is thrown?

8. Lot throws a ball at an initial speed of 12 m/s at an angle of 30° south of east from 830 meters above the surface of the Earth.

a. Complete the table:

$x_i =$	$y_i =$
$v_{i,x} =$	$v_{i,y} =$
$a_x =$	$a_y =$

b. How long will the ball be in the air for?

c. What will be the range of the ball?

d. How long after the ball is thrown does it take to reach 400 m above the surface of the Earth?

e. How high above the surface of the Earth will the ball be four seconds after it is thrown?

f. How far horizontally does the ball travel during the first four seconds after it is thrown?

- g. What will be the velocity of the ball (number and direction) four seconds after it is thrown?

- h. What will be the displacement of the ball (number and direction) four seconds after it is thrown?

9. A 25 kg ball is thrown from the edge of a very tall building with an initial speed of 20 m/s at an angle of 60° north of east. There is an infinitely tall vertical wall 120 m from the building.

a. Draw a figure.

b. Complete the table:

$x_i =$	$y_i =$
$v_{i,x} =$	$v_{i,y} =$
$a_x =$	$a_y =$

c. How much time does it take for the ball to hit the wall?

d. At which height above or below the original position where the ball is thrown will the ball hit the wall?

e. What will be the velocity of the ball (number and direction) when it hits the wall?

- f. What will be the displacement of the ball (number and direction) when it hits the wall?

Name: _____

Class: _____

Due Date: _____

A.2 Forces and Momentum

Understandings

- Newton's three laws of motion.
- Forces as interactions between bodies.
- Forces acting on a body can be represented in a free-body diagram.
- Free-body diagrams can be analyzed to find the resultant force on a system.
- The nature and use of the following contact forces:
 - The normal force F_N is the component of the contact force acting perpendicular to the surface that counteracts the body
 - The surface frictional force F_f acting in a direction parallel to the plane of contact between a body and a surface, on a stationary body as given by $F_f \leq \mu_s F_N$ or a body in motion as given by $F_f = \mu_d F_N$ where μ_s and μ_d are the coefficients of static and dynamic friction respectively.
 - The elastic restoring force F_H following Hooke's law as given by $F_H = -kx$ where k is the spring constant.
 - The viscous drag force F_d acting on a small sphere opposing its motion through a fluid as given by $F_d = 6\pi\eta rv$ where η is the fluid viscosity, r is the radius of the sphere, and v is the velocity of the sphere through the fluid.
 - The buoyancy F_b acting on a body due to the displacement of the fluid as given by $F_b = \rho Vg$ where V is the volume of the fluid displaced.
- The nature and use of the following field forces:
 - The gravitational force F_g as the weight of the body and calculated as given by $F_g = mg$.
 - The electric force F_e .
 - The magnetic force F_m .
- Linear momentum is given by $p = mv$ remains constant unless the system is acted upon by a resultant external force.
- A resultant external force applied to a system constitutes an impulse J as given by $J = F\Delta t$ where F is the average resultant force and Δt is the time of contact.
- The applied external impulse equals the change in momentum of the system.

- Newton's second law in the form $F = ma$ assumes mass is constant whereas $F = \frac{\Delta p}{\Delta t}$ allows for situations where mass is changing.
- The elastic and inelastic collisions of two bodies.
- Explosions.
- Energy considerations in elastic collisions, inelastic collisions, and explosions.
- Bodies moving along a circular trajectory at a constant speed experience an acceleration that is directed radially towards the center of the circle – known as centripetal acceleration as given by $a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$.
- Circular motion is caused by a centripetal force acting perpendicular to the velocity.
- A centripetal force causes the body to change direction even if its magnitude of velocity may remain constant.
- The motion along a circular trajectory can be described in terms of the angular velocity ω which is related to the linear speed v by the equation as given by $v = \frac{2\pi r}{T} = \omega r$.

Equations

$$F_f \leq \mu_s F_N$$

$$p = mv$$

$$F_f = \mu_d F_N$$

$$J = F\Delta t$$

$$F_H = -kx$$

$$F = ma = \frac{\Delta p}{\Delta t}$$

$$F_d = 6\pi\eta r v$$

$$a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$$

$$F_b = \rho V g$$

$$v = \frac{2\pi r}{T} = \omega r$$

$$F_g = mg$$

The solutions can be found on the YouTube channel Go Physics Go:

<https://www.youtube.com/@gophysicsgo/playlists>

Part 1: Use your favorite sources to answer the following questions

1. What is the meaning and equation of *directly proportional*? *Inversely proportional*? Give an example of each.

2. What is *mass*? What are its units? Is it a scalar or vector?

3. What is a *force*? What are its units? Is it a scalar or vector? How many objects are needed for a *force*?

4. What is the *force of gravity*? This is also called *weight*.

5. What are the equations for the *force of gravity*
 - a. if we are near the surface of a planet?

 - b. in general (this is called *Newton's Law of Gravitation*)?

6. What are some differences between *mass* and *weight*?
7. What is the *normal force*? In which direction does it point? Draw an image.
8. What is the *force of friction*? In which direction does it point? Draw an image.
9. What is the equation for *surface friction*? Define each variable.
10. What is the meaning of *dynamic/kinetic*? *Static*? Which is greater: *kinetic friction* or *static friction*?
11. What is the meaning of a *rough surface*? A *smooth surface*?
12. For which object do we use the *force of tension*? Draw an image.

13. What is the equation for the *spring force*? Define each variable. What is the name and what are the units of k in the spring force equation?
14. Draw a *force vs. displacement* graph for a mass on a spring. What does the slope of a *force vs. displacement* graph tell us? What does the area under a *force vs. displacement* graph tell us?
15. What is the *buoyant force*? State its equation and define each variable.
16. State the equation for the viscous drag force acting on a small sphere opposing its motion through a fluid. Define each variable.
17. How do we draw a *free body diagram*? Here are the steps:
- Circle the object (or objects) in question
 - Label all the external/outside forces on the object (or objects) with an arrow to show the direction and magnitude of each force
 - Draw a convenient axis to minimize vector components
 - For each object apply Newton's second law of motion for each axis

18. Label the forces on the following diagrams.

1. A block is at rest on a horizontal surface.



2. A man is pushing a block to the left with a horizontal force on a rough horizontal surface. The block does not move.

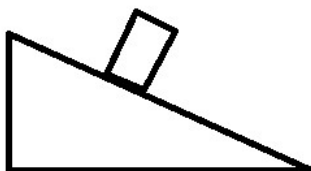


3. An object is being pushed to the left on a wall. The object does not move.

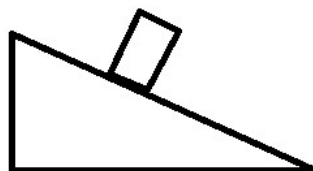


4. A man is pushing a block on a slope which is 20° from the horizontal on a rough horizontal surface. The block does not move.

The man is pushing the block downwards.



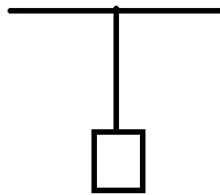
The man is pushing the block upwards.



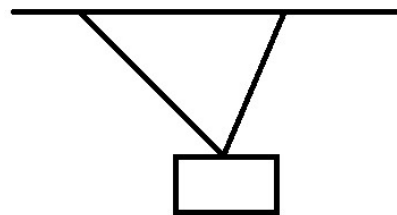
5. A dead fish is floating on top of the plastic radioactive ocean water.



6. A block is at rest and is hanging from the ceiling by one massless string.

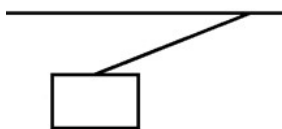


7. A block is at rest and is hanging from the ceiling by two massless strings.

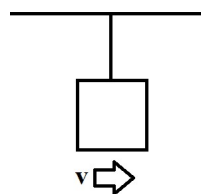


8. A block is tied to a massless string and is raised up at an angle θ from the vertical.

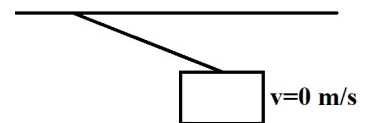
The block is released
from rest.



The block is now at the
bottom of its motion.



The block is now at the
top of its motion.



9. A car is moving in a straight line to the right with a constant speed

on a smooth horizontal surface.



on a rough horizontal surface.



10. A car is moving in a straight line to the right on a rough horizontal surface.

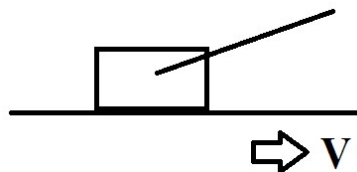
The car is slowing down (decelerating).



The car is speeding up (accelerating).



11. A man pulls a massless string which is attached to a block with a constant speed at an angle θ above the horizontal on a rough surface. Label the forces on the block, not the man.



12. A ball is thrown vertically up and is moving upwards.

There is **no** force of air friction.



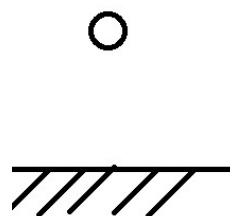
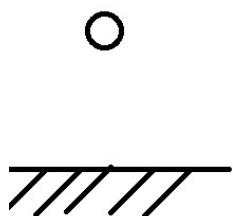
There **is** a force of air friction.



13. A ball is thrown vertically up and is at its maximum height.

There is **no** force of air friction.

There **is** a force of air friction.

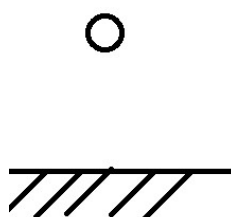
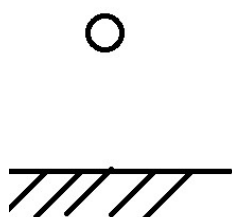


14. A ball is **dropped** from rest from the top of a very tall building. There is no force of air friction. Draw a free body diagram of the ball

the moment the ball is
dropped.

when the ball is halfway
down.

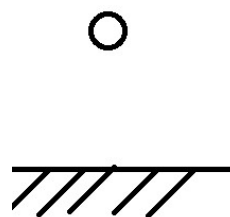
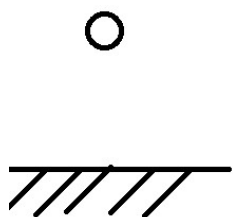
just before ball strikes
the ground.



15. A ball is **thrown** downwards from the top of a tall building. Draw a free body diagram of the ball the moment after the ball is thrown when

there is **no** force of air friction.

there **is** a force of air friction.



16. A ball is released from rest from the top of a very tall building. There is air friction. Draw a free body diagram of the ball....

a few seconds before the ball reaches its terminal velocity.



the exact moment the ball reaches its terminal velocity.



a few seconds after the ball reaches its terminal velocity.



17. A ball is thrown at an angle $\theta = 45^\circ$ north of east from a horizontal surface. Draw a free body diagram of the ball the moment the ball is thrown when

there is **no** force of air friction.



there **is** a force of air friction.



18. A ball is thrown at an angle $\theta = 45^\circ$ north of east from a horizontal surface. The ball is at its maximum vertical height.

There is **no** force of air friction.

There **is** a force of air friction.

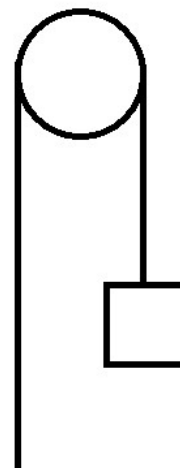
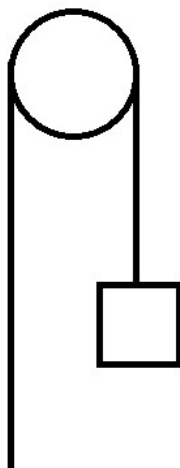
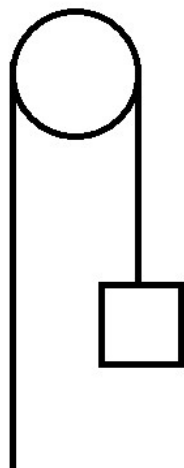


19. A block is being pulled vertically upwards by a massless string pulley.

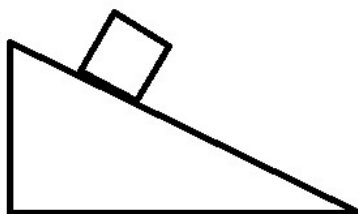
The speed of the block is constant.

The block is accelerating.

The block is slowing down (decelerating).

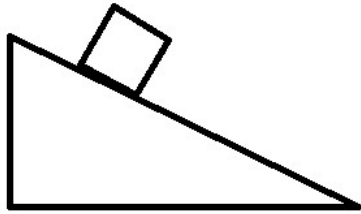


20. A block is at rest on an incline. There is surface friction.

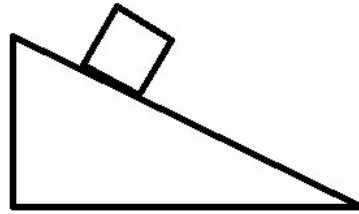


21. A block moves down an incline. There is surface friction.

The speed of the block is constant.

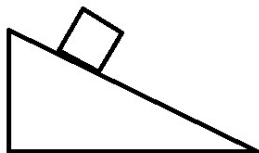


The block accelerates.

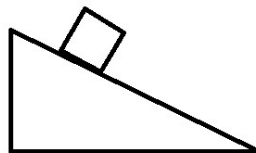


22. A block is pushed up an incline. There is surface friction.

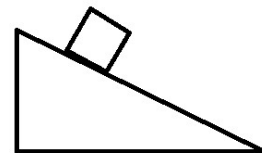
The block slows down
(decelerates).



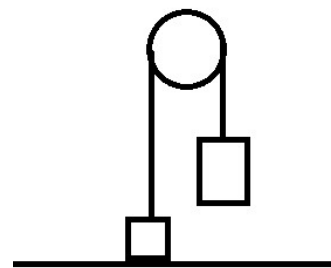
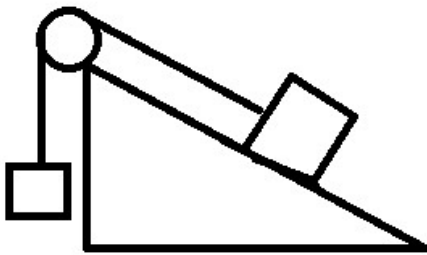
The speed of the block
is constant.



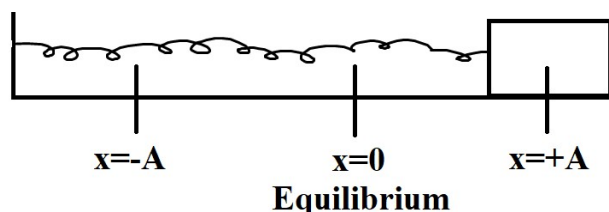
The block speeds up
(accelerates).



23. Two blocks are attached to each other by a common string. There is surface friction.



24. A mass lying on a rough horizontal surface is attached to a spring and is stretched from its equilibrium position. It is then released.



19. What is the meaning of *inertia*? What is *inertia* directly proportional to?

20. State the name of *Newton's first law of motion*. State the definition/meaning of *Newton's first law of motion*.

21. Why is it not safe to stand up when a bus, plane, or subway is moving?

22. State the name of *Newton's second law of motion*. Give the equation for *Newton's second law of motion*.

23. True or false:

- a. According to Newton's second law of motion $\sum \vec{F}$ and \vec{a} will always point in the same direction.
- b. According to Newton's second law of motion $\sum \vec{F}$ and \vec{v} will always point in the same direction. In other words, there must be a net force in the same direction as the motion of the object.
- c. According to Newton's second law of motion \vec{v} and \vec{a} will always point in the same direction.

24. Give an example of an object when its net force (or acceleration) and velocity point in opposite directions.

25. What is the meaning of *static equilibrium*? What is the meaning of *translational/dynamic equilibrium*?

26. A 14 kg mass is at rest on a horizontal surface.

a. Draw a free body diagram.



b. What is the force of gravity acting on the object?

c. What is the normal force acting on the object?

27. Ishmael pushes a 16 kg block to the left on a rough horizontal surface with a force of 70 N. The block does not move.

a. Draw a free body diagram.



b. What is the force of gravity acting on the object?

c. What is the normal force acting on the object?

d. What is the force of friction exerted on the block?

e. What is the coefficient of static friction?

28. Isaac pushes a 18 kg block to the left on a smooth horizontal surface with a force of 70 N.

a. Draw a free body diagram.



b. What is the force of gravity acting on the object?

c. What is the normal force acting on the object?

d. What is the horizontal acceleration of the block?

e. What is the vertical acceleration of the block?

29. Jacob pushes a 20 kg block to the left on a rough horizontal surface with a force of 70 N. The block moves at a constant speed of 2 m/s.

- a. Draw a free body diagram.



- b. What is the force of gravity acting on the object?
- c. What is the normal force acting on the object?
- d. What is the horizontal acceleration of the block?
- e. What is the vertical acceleration of the block?
- f. What is the force of friction exerted on the block?
- g. What is the coefficient of friction μ between the block and the surface?

30. Adam pushes a block with a mass of 24 kg to the right on a rough horizontal surface with a coefficient of kinetic friction of 0.3. The block moves with a constant acceleration of $2 \frac{\text{m}}{\text{s}^2}$.

- a. Draw a free body diagram.



- b. What is the force of gravity acting on the object?
- c. What is the normal force acting on the object?
- d. What is the force of friction exerted on the block?
- e. What is the force of push given to the block?

31. Joseph is pulling a 65 kg block with a force of 800 N at an angle of 45 degrees north of east above the horizontal of a rough horizontal surface. The coefficient of friction between the block and the surface is $\mu = 0.3$.

a. Draw a free body diagram.



b. What is the vertical acceleration of the block?

c. What is the normal force acting on the block?

d. What is the horizontal acceleration of the block?

32. An 80 kg man is standing on a scale in an elevator. Determine the reading on the scale when

a. the elevator is at rest.

b. the elevator is moving up with a constant speed of $2 \frac{\text{m}}{\text{s}}$.

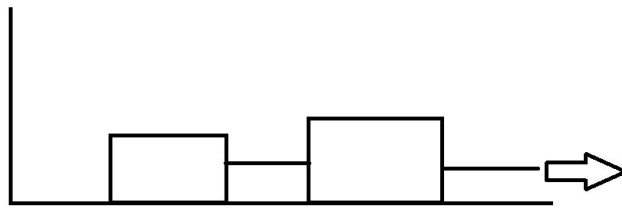
c. the elevator is moving down with a constant speed of $2 \frac{\text{m}}{\text{s}}$.

d. the elevator moves upwards with a constant acceleration of $2 \frac{\text{m}}{\text{s}^2}$.

e. the elevator moves downwards with a constant acceleration of $2 \frac{\text{m}}{\text{s}^2}$.

33. A block with a mass $m_2 = 20$ kg is on a rough horizontal surface with a coefficient of friction of $\mu = 0.4$. Attached to the right of m_2 is a massless string which is pulling m_2 to the right with a force of tension F_{tension} . Attached to the right of the massless string is another block of mass $m_1 = 30$ kg. Attached to the right of m_1 is another massless string which pulls the whole system with a constant pulling force $F_{\text{pull}} = 800$ N and constant acceleration a .

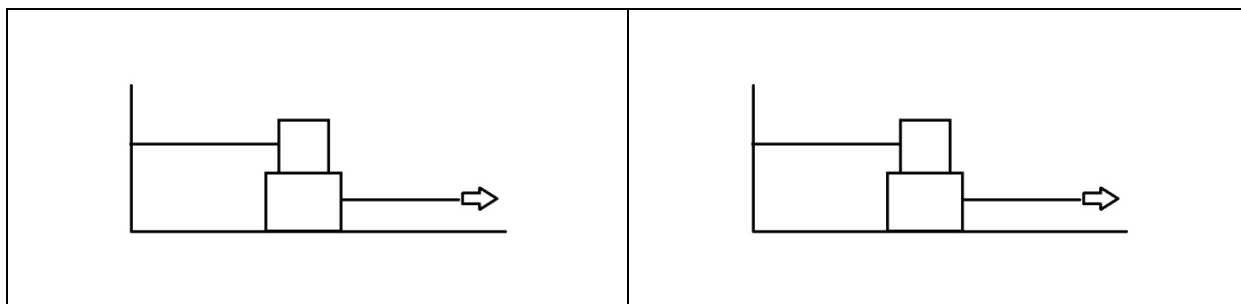
a. Draw a free body diagram.



- b. Find the acceleration of the whole system a .
c. Find the force of tension F_{tension} of the massless string which attaches both masses.

34. A block with a mass $m_2 = 15 \text{ kg}$ is on a rough horizontal surface. There is a string pulling it to the right with a force F_{pull} at a constant speed. Above m_2 there is a block with a mass $m_1 = 12 \text{ kg}$. There is a string attached to the left of m_1 which is attached to a wall which has a force of tension $F_{tension}$. The coefficient of friction between m_1 and m_2 is $\mu_{1,2} = 0.25$ and the coefficient of friction between m_2 and the surface is $\mu_{2,surface} = 0.35$.

a. Draw a free body diagram for each object.

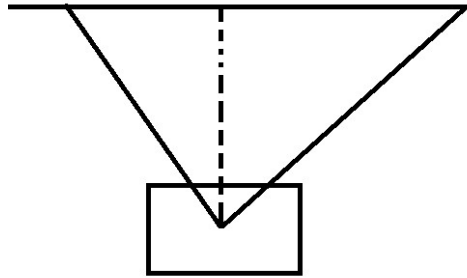


b. Find $F_{tension}$.

c. Find F_{pull} .

35. A 12 kg block is held in the air by two strings attached to the wall. The first string makes an angle of $\theta_1 = 60^\circ$ north of west. The second string makes an angle of $\theta_2 = 45^\circ$ north of east.

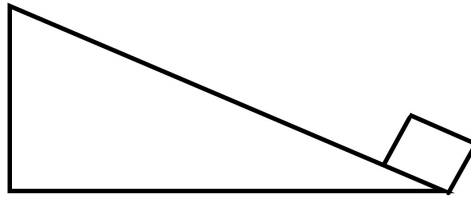
a. Draw a free body diagram.



b. Find the force of tension on each string.

36. A block with mass 15 kg is at rest on the bottom of an incline with $\theta = 25^\circ$ which is 35 m long. The coefficient of friction between the block and the surface is $\mu = 0.45$. A man pushes the block up parallel to the incline with a force of 155 N.

a. Draw a free body diagram.



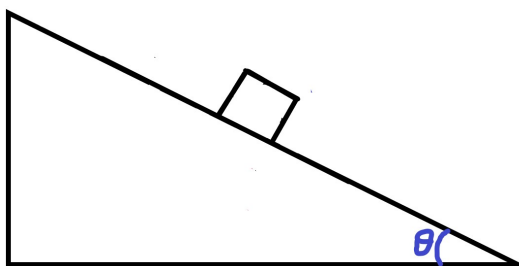
b. What is the acceleration of the block?

c. What will be the final speed of the block when it reaches the top of the incline?

d. How long will it take for the block to reach the top of the incline?

37. A block with mass 65 kg is initially at rest in the middle of an incline with $\theta = 25^\circ$ which is 40 m long. The coefficient of friction between the block and the surface is $\mu = 0.45$. A man pushes the block down parallel to the incline with a force of 60 N. The block accelerates downwards at a constant rate. Let the acceleration from gravity be $\vec{g} = 9.81 \frac{\text{m}}{\text{s}^2}$.

a. Draw a free body diagram.



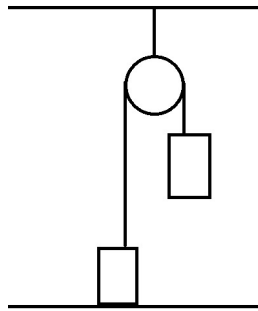
b. What is the magnitude of the acceleration of the block?

c. What will be the final speed of the block when it reaches the bottom of the incline?

d. How long will it take for the block to reach the bottom of the incline?

38. A massless frictionless pulley is attached to a ceiling. Mass $m_1 = 16 \text{ kg}$ is at rest on the ground. It is attached to a massless string which goes over the massless frictionless pulley and is attached to another mass $m_2 = 46 \text{ kg}$ which is also initially at rest in the air. m_2 is released from rest and both masses accelerate at a constant rate.

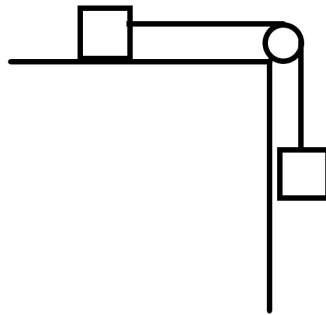
a. Draw a free body diagram.



- b. Find the common acceleration of the system.
c. Find the force of tension F_{tension} of the massless string.

39. A block of mass $m_1 = 12 \text{ kg}$ sits at rest on a horizontal surface with $\mu = 0.24$. Mass m_1 is attached to a massless string which goes over a massless pulley which is attached to another block of mass $m_2 = 36 \text{ kg}$.

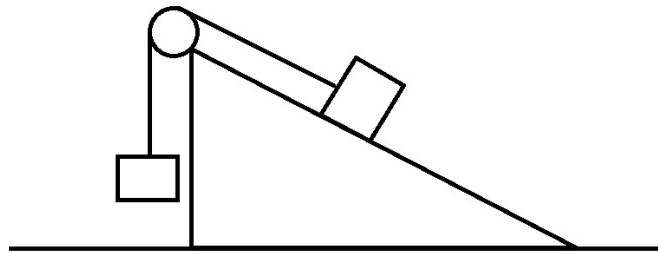
a. Draw a free body diagram.



b. What is the common acceleration of the blocks?
c. What is the force of tension on the string?

40. A 4 kg mass m_1 is initially at rest on a $\theta = 30^\circ$ incline. The surface has a coefficient of friction $\mu = 0.4$. The 4 kg mass has a massless string attached to it which goes over the top of the incline above a frictionless pulley to another mass m_2 of 18 kg which is hanging in the air. Both objects are released from rest and move with a constant acceleration. m_2 moves down while m_1 moves up the incline.

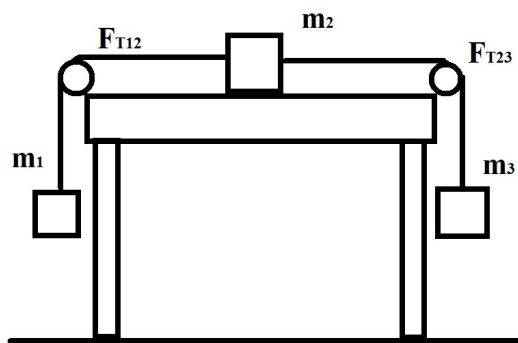
a. Draw a free body diagram.



- b. What will be the common acceleration of each object?
c. What will be the force of tension on the string?

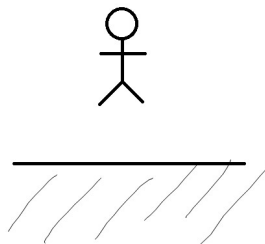
41. A block with mass $m_2 = 8 \text{ kg}$ is held at rest on a rough horizontal table which has a coefficient of friction of $\mu = 0.2$. It is attached by a string to a mass $m_3 = 14 \text{ kg}$ which hangs to the right of the table and another string to a mass $m_1 = 2 \text{ kg}$ which hangs to the left of table as shown below. Mass m_2 is released from rest and the whole system accelerates with a constant rate.

a. Draw a free body diagram.



- b. Determine the acceleration of the system.
 c. Determine the force of tension of string F_{T12} and the force of tension of string F_{T23} .

42. State the name of *Newton's third law of motion*. State the equation for *Newton's third law of motion*.
43. Give three examples of *Newton's third law of motion* (For each example you need two sentences: one for the action and one for the reaction.). Three examples have been given to you:
- a. Man pushes wall forward. Wall pushes man backwards.
 - b. Fish pushes water backwards. Water pushes fish forwards.
 - c. Earth pulls man down. Man pulls Earth up.
 - d.
 - e.
 - f.
 - g.
44. An 80 kg man on Earth jumps vertically upwards. The acceleration due to gravity near the surface of the Earth is approximately $9.81 \frac{\text{m}}{\text{s}^2}$. The mass of the Earth is approximately 5.97×10^{24} kg. Use Newton's third law of motion to determine the acceleration of the Earth after the man jumps.



45. **Use a pencil and ruler!** Define *free fall*. Draw a *displacement vs. time* graph, a *distance vs. time* graph, a *velocity vs. time* graph, a *speed vs. time* graph, and an *acceleration vs. time* graph for an object dropped from rest in free fall.

46. **Use a pencil and ruler!** Define *terminal velocity*. What is the relationship between speed and the force of friction? Draw a *distance vs. time* graph, a *speed vs. time* graph, and an *acceleration vs. time* graph of an object being dropped from rest from a very high height above the surface of the Earth with both the force of friction and the force of gravity acting on it.

47. Use Newton's third law of motion to complete the next sentence: Man throws rock forward.
48. What is the meaning and equation for *impulse* \vec{J} ? Do not confuse impulse \vec{J} with current I !
49. What is the meaning, symbol, equation, and fundamental units for *momentum* \vec{p} ? Momentum is also called "*inertia in motion*." Why? Do not confuse momentum \vec{p} with pressure P or power P or density ρ !
50. Why are the front of cars built so weak? Why are cars so easy to damage during an accident?
51. Why do athletes have their elbows bent when catching a ball? Why do athletes have their knees bent when coming down after jumping?
52. What common mistake do people make when firing/shooting a gun?
<https://www.youtube.com/watch?v=bYWzMDVgweg>

53. What does the law of *conservation of momentum* tell us? What is the equation for the law of conservation of momentum?
54. What is an *elastic collision*? Is momentum conserved? Is kinetic energy conserved? Is total energy conserved?
55. What is an *inelastic collision*? Is momentum conserved? Is kinetic energy conserved? Is total energy conserved?
56. What is a *perfectly inelastic collision*? Is momentum conserved? Is kinetic energy conserved? Is total energy conserved?
57. What does the area under a *force vs. time graph* tell us?
58. What does the slope of a line on a *force vs. time graph* tell us?
59. A 2 kg block is moving east with a speed of 5 m/s. It hits a wall and rebounds to the west at a speed of 4 m/s. What is the magnitude and direction of the change in momentum of the block?

60. A 2 kg block is moving east on a frictionless surface with a speed of 5 m/s. It then moves on a rough surface for three seconds. Finally it continues to move east on a frictionless surface with a new speed of 1 m/s. What is the force of friction of the rough surface?
61. A 3 kg block is moving west at 4 m/s on a frictionless horizontal surface. A 5 kg block is moving east at 6 m/s on the same surface. Both of them collide and stick together.
- What is the final speed and direction of the block?
 - Is momentum conserved?
 - What is the original total kinetic energy?
 - What is the final total kinetic energy?
 - Is kinetic energy conserved?
 - Is this an elastic or inelastic collision?
 - Is total energy conserved?

62. A 7 kg block is moving north at 8 m/s on a frictionless horizontal surface. A 9 kg block is moving south at 10 m/s on the same surface. They collide. The 7 kg block is now moving south at 4 m/s.

a. What is the final speed and direction of the 9 kg block?

b. Is momentum conserved?

c. What is the original total kinetic energy?

d. What is the final total kinetic energy?

e. Is kinetic energy conserved?

f. Is this an elastic or inelastic collision?

g. Is total energy conserved?

63. A 12 kg block is initially at rest on a frictionless horizontal surface. It then explodes into three pieces. A 3 kg block moves west at 4 m/s. A 5 kg block moves east at 6 m/s.

a. What is the final speed and direction of the 4 kg block?

b. Is momentum conserved?

c. What is the original total kinetic energy?

d. What is the final total kinetic energy?

e. Is kinetic energy conserved?

f. Is total energy conserved?

64. A 12 kg block is moving east at 13 m/s on a frictionless horizontal surface. It then explodes into three pieces. A 4 kg block moves west at 5 m/s. A 6 kg block moves east at 7 m/s.

- a. What is the final speed and direction of the 2 kg block?

- b. Is momentum conserved?

- c. What is the original total kinetic energy?

- d. What is the final total kinetic energy?

- e. Is kinetic energy conserved?

- f. Is total energy conserved?

65. A 4 kg block is moving east at 5 m/s on a frictionless horizontal surface. It collides with a 6 kg block initially at rest. The 4 kg block then moves northeast at 3 m/s at an angle of 30° above the horizontal.

a. **Use a pencil!** Draw an initial and final figure.

Initial	Final

b. Use the law of conservation of momentum for each axis to determine the final speed (in m/s) and direction (in degrees) of the 6 kg block.

- c. Is momentum conserved?
- d. What is the original total kinetic energy?
- e. What is the final total kinetic energy?
- f. Is kinetic energy conserved?
- g. Is this an elastic or inelastic collision?
- h. Is total energy conserved?

66. Define *centripetal*.

67. Define *centrifugal*.

68. Are there *centripetal forces*?

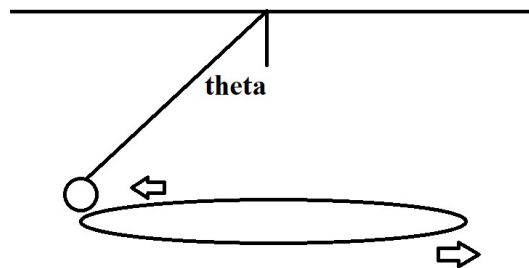
69. Are there *centrifugal forces*?

70. Imagine driving in a straight line with a constant speed of 60 km/h. You then quickly make a right turn. Do you feel a force? In which direction? Is it a centripetal force or a centrifugal force? Is it a real force? Why?

71. In circular motion how much work does the centripetal force do? Use the equation $W = \vec{F} \vec{d} \cos \theta$.

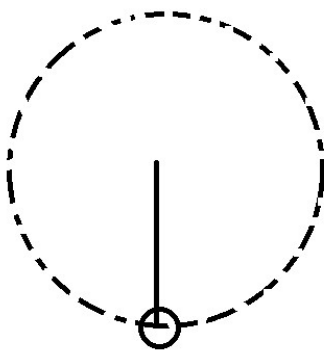
72. Label the forces on the following diagrams.

- a. An object is attached to a string. The object moves in a horizontal circle at an angle θ from the vertical.

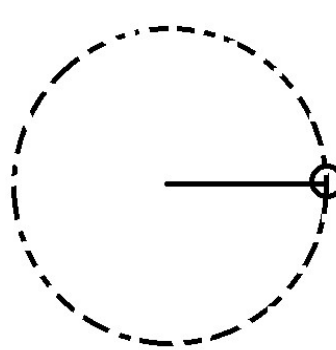


- b. An object is attached to a string. The object moves in a vertical loop. Draw a free body diagram when the object is

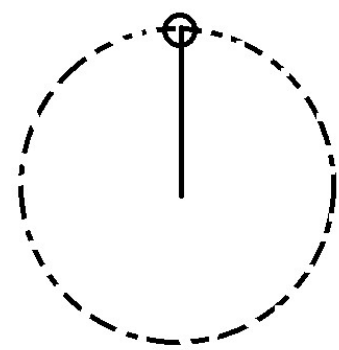
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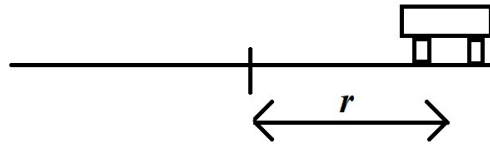
halfway to the top.



at the top.



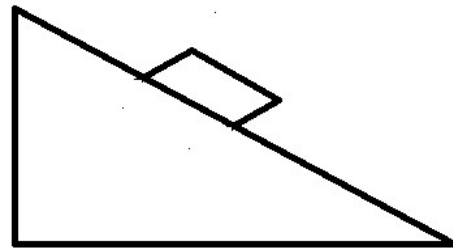
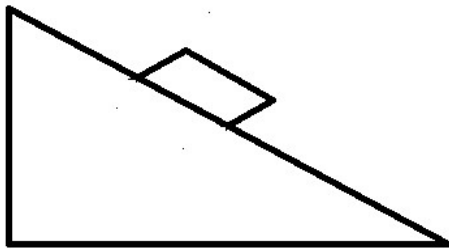
- c. A car moves in a horizontal circle at a constant speed with a radius r .



- d. A car moves in a circle on a banked road (cone) with a constant radius r .
There is force of friction.

a. The car is moving slow.

b. The car is moving fast.

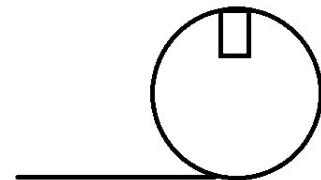
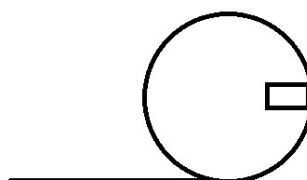
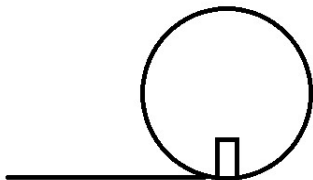


- e. A cart is moving up on a vertically circular roller coaster with a radius r .
There is no force of friction.

The cart is at the bottom.

The cart is at a height r .

The cart is at the top.

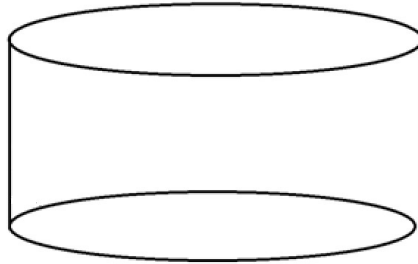


- f. A fast motorcycle moves around a nonmoving cylindrical wall.

"Mauth Ka Kua" (The Well Of Death): Basic physics at its best!

Swastik Ghosh

<https://www.youtube.com/watch?v=cFLNknvi7QE>

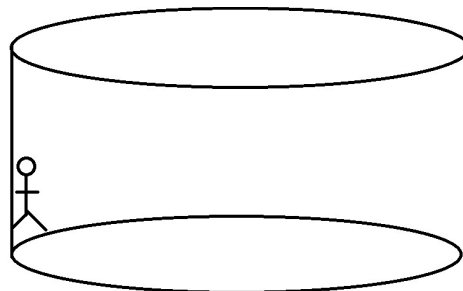


- g. A man is on the edge of a moving cylindrical wall.

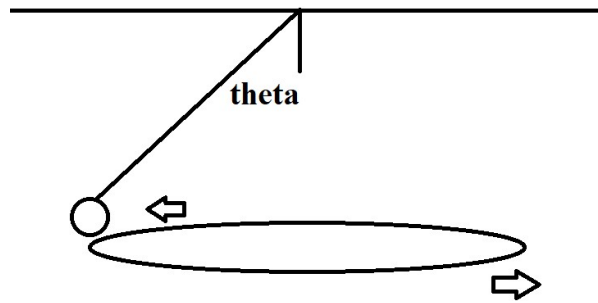
CENTRIFUGEUSE - ROTOR @ FOIRE DU TRONE (GoPro)

josselinz86

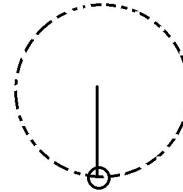
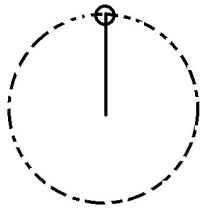
<https://www.youtube.com/watch?v=GspwbZSjABA>



73. Draw a free body diagram and use Newton's second law of motion to obtain an equation for the force of tension and then the speed of a mass on a string in horizontal circular motion which makes an angle θ from the vertical. Your answer should be in terms of the mass of the object m , the length of the string l , the angle from the vertical θ , and the acceleration from gravity g .

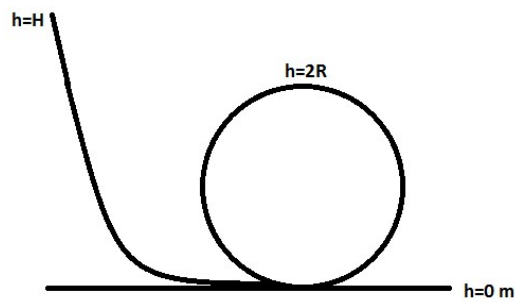


74. A point mass is attached to a massless string with length r . The mass and string are moving in vertical circular motion with a constant speed v . Draw free body diagrams and use Newton's second law of motion to obtain equations of the force of tension at the top and bottom of the string. Where is the force of tension greater? Your answers should be in terms of the mass of the object m , the radius of the string r , the speed of the point mass v , and the acceleration from gravity g .



Let all the forces which point towards the center be positive and all the forces which point away from the center be negative.

75. An object is released from rest from a height H . First use the law of conservation of energy to obtain an equation for the speed of the object when it has reached the top of the loop of the roller coaster. Then use Newton's second law of motion to obtain an equation for the normal force on the object when it has reached the top of the loop of the roller coaster. Your answer for the normal force should be in terms of the mass of the object m , the initial height of the object H , the radius of the loop r , and the acceleration from gravity g .



Roller coaster loop the loop

Matt Anderson

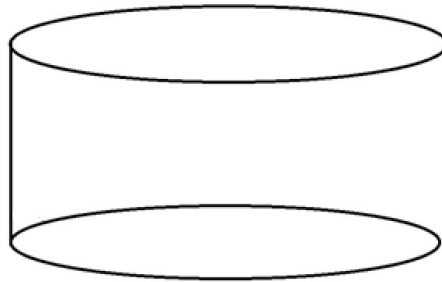
https://www.youtube.com/watch?v=upjI5dw8_Es

76. Draw a free body diagram and use Newton's second law of motion to obtain an equation for the speed of an object in the amusement park ride "The Well of Death." Your answer should be in terms of the radius of the cylinder/well R , the coefficient of friction μ , and the acceleration from gravity g .

"Mauth Ka Kua" (The Well Of Death): Basic physics at its best!

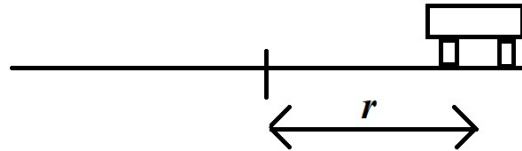
Swastik Ghosh

<https://www.youtube.com/watch?v=cFLNknvi7QE>

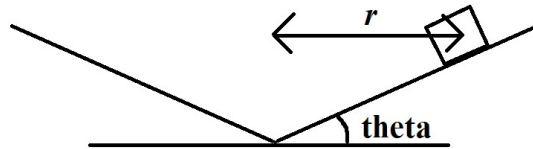


77. Cars

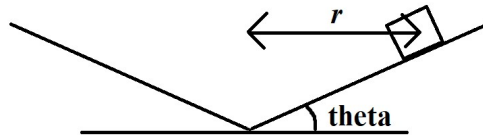
- a. Use Newton's second law of motion to find an equation for the speed of a car moving in circular motion on a horizontal road with surface friction. Your answer should be in terms of the radius of the track r , the coefficient of friction μ , and the acceleration from gravity g .



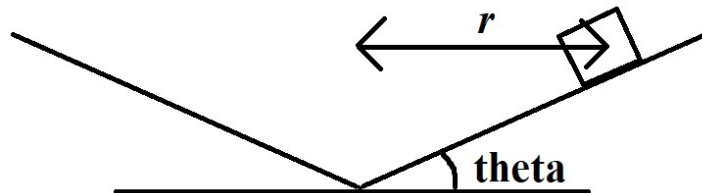
- b. Use Newton's second law of motion to find an equation for the speed of a car moving at an angle θ to the horizontal in circular motion on a banked/angled road with no friction. Your answer should be in terms of the radius of the track r , the angle of the banked road θ , and the acceleration from gravity g .



- c. Use Newton's second law of motion to find an equation for the speed of a **slow moving car** moving at an angle θ to the horizontal in circular motion on a banked/angled road with surface friction. Your answer should be in terms of the radius of the track r , the angle of the banked road θ , the coefficient of friction μ , and the acceleration from gravity g .



- d. Use Newton's second law of motion to find an equation for the speed of a **fast moving car** moving at an angle θ to the horizontal in circular motion on a banked/angled road with surface friction. Your answer should be in terms of the radius of the track r , the angle of the banked road θ , the coefficient of friction μ , and the acceleration from gravity g .



78. Write down the common terms and equations for circular motion.

If you are interested in learning about circular motion and space travel then please read the book *Project Mars* by Dr. Wernher von Braun.

Name: _____

Class: _____

Due Date: _____

A.3 Work, Energy, and Power

Understandings

- The principle of the conservation of energy.
- Work done by a force is equivalent to a transfer of energy.
- Energy transfers can be represented on a Sankey diagram.
- Work W done on a body by a constant force depends on the component of the force along the line of displacement as given by $W = Fs \cos \theta$.
- Work done by the resultant force on a system is equal to the change in the energy of the system.
- Mechanical energy is the sum of kinetic energy, gravitational potential energy, and elastic potential energy.
- In the absence of frictional, resistive forces, the total mechanical energy of a system is conserved.
- If mechanical energy is conserved, work is the amount of energy transformed between different forms of mechanical energy in a system such as
 - the kinetic energy of translational motion as given by $E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
 - the gravitational potential energy, when close to the surface of the Earth as given by $\Delta E_p = mg\Delta h$
 - the elastic potential energy as given by $E_H = \frac{1}{2}k\Delta x^2$
- Power developed P is the rate of work done, or the rate of energy transfer, as given by $P = \frac{\Delta W}{\Delta t} = Fv$
- Efficiency η in terms of energy transfer or power as given by $\eta = \frac{E_{\text{output}}}{E_{\text{input}}} = \frac{P_{\text{output}}}{P_{\text{input}}}$
- Energy density of the fuel sources.

Equations

$$W = Fs \cos \theta$$

$$E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

$$\Delta E_p = mg\Delta h$$

$$E_H = \frac{1}{2}k\Delta x^2$$

$$P = \frac{\Delta W}{\Delta t} = Fv$$

$$\eta = \frac{E_{\text{output}}}{E_{\text{input}}} = \frac{P_{\text{output}}}{P_{\text{input}}}$$

Equation not given in IB Physics Data Booklet:

$$W = \Delta E_k = E_{k,f} - E_{k,i}$$

6. What is the meaning of *gravitational potential energy*? What is the equation for *gravitational potential energy* of an object near the surface of a planet? Define each variable. What is the general equation for the *gravitational potential energy* between two objects? Define each variable.

7. What is the equation for the *elastic potential energy* of a compressed or stretched spring? Define each variable. What is the meaning and units for the *spring constant k*?

8. What is the equation for the *total mechanical energy* of an object?

9. True or false: Work is done on an object if the object moves.

10. What is the work done on a 3 kg rock if it travels 60 m with a constant speed of 4 m/s in outer space?
11. What does the slope of a *force vs. displacement* graph tell us?
12. What does the area under a *force vs. displacement* graph tell us?
13. What is the meaning of *power P*? Equation? Units? Is it a scalar or vector? Do not confuse power P with pressure P or momentum \vec{p} or density ρ !
14. What is the meaning of and the equation for the *law of conservation of energy*?
15. State the equation for the work-energy theorem.
16. What are some characteristics of a *Sankey diagram*? Sketch a simple *Sankey diagram*.
<http://sankeymatic.com/>
17. What is *efficiency*? Equation? Units? Is it a scalar or vector?

2. A 10 kg object initially at rest is 12 m above the surface of the Earth. It is released. There is no air friction.
- Draw a figure.
 - What is the initial kinetic energy of the object?
 - What is the initial gravitational potential energy of the object?
 - What is the initial total energy of the object?
 - What is the kinetic energy of the object when it is halfway to the surface?
 - What is the gravitational potential energy of the object when it is halfway to the surface?
 - What is the total energy of the object when it is halfway to the surface?
 - What is the final gravitational potential energy of the object just before it reaches the surface?

- i. What is the final kinetic energy of the object just before it reaches the surface?

- j. What is the total energy of the object just before it reaches the surface?

- k. What is the final speed of the object just before it reaches the ground?
From part d the total energy of the object is $1,177.2 \text{ J}$.

- l. Draw a *gravitational potential energy vs. height* graph, a *kinetic energy vs. height* graph, and a *total energy vs. height* graph.

3. Jethro throws a 5 kg object from the surface of the Earth vertically upwards with an initial speed of 8 m/s. There is no air friction.
- a. Draw a figure.

 - b. What is the initial gravitational potential energy of the object?

 - c. What is the initial kinetic energy of the object?

 - d. What is the initial total energy of the object?

 - e. What is the maximum height the object will travel?

 - f. How long will it take for the object to reach its maximum height?

 - g. What is the gravitational potential energy of the object when it is halfway to its maximum height?

 - h. What is the kinetic energy of the object when it is halfway to its maximum height?

 - i. What is the total energy of the object when it is halfway to its maximum height?

- j. What is the gravitational potential energy of the object when it reaches its maximum height?
- k. What is the kinetic energy of the object when it reaches its maximum height?
- l. What is the total energy of the object when it reaches its maximum height?
- m. What is the speed of the object when it reaches its maximum height?
- n. Draw a *gravitational potential energy vs. height* graph, a *kinetic energy vs. height* graph, and a *total energy vs. height* graph.

4. A 8 kg object is falling vertically freely with a speed of 40 m/s at an elevation of h_1 . What will be the speed of the object after it has fallen a distance of 70 m? Round your answer to two decimal places.

6. A 7 kg object is placed on a 12 m long smooth incline which is 30° above the horizontal. It is released and slides down.
- Draw a figure.
 - What is the initial height of the object?
 - What is the initial gravitational potential energy of the object?
 - What is the initial kinetic energy of the object?
 - What is the initial total energy of the object?
 - What is the final speed of the object when it reaches the bottom of the incline?
 - What is the final kinetic energy of the object?
 - What is the final gravitational potential energy of the object?
 - What is the acceleration of the object?
 - How long does it take for the object to reach the bottom of the incline?

7. A 4 kg block is placed on a 20 m long rough incline which is 30° above the horizontal. The coefficient of friction between the block and the incline is $\mu = 0.3$. The block is released and slides down.

a. Draw a figure.

b. What is the initial height of the object?

c. What is the initial gravitational potential energy of the object?

d. What is the initial kinetic energy of the object?

e. What is the initial total energy of the object?

f. What is the normal force acting on the block?

g. What is the force of friction acting on the block?

h. What is the final speed of the object when it reaches the bottom of the incline?

i. What is the acceleration of the object?

j. What is the final kinetic energy of the object?

k. What is the final gravitational potential energy of the object?

l. What is the final total energy of the object?

m. How long will it take for the object to reach the bottom of the incline?

n. How much energy was lost by the block?

8. A 6 kg block is moving to the right with a constant speed of 22 m/s on a horizontal frictionless surface. The block then goes up a 30° incline which has a coefficient of friction of 0.8.

a. Draw a figure.

b. How many meters up the incline and how high does the block move?

9. A horizontal spring with a spring constant $k = 3,000 \frac{\text{N}}{\text{m}}$ is compressed 6 cm by an 800 gram block which is resting on a frictionless surface. The block is then released from rest.

a. Draw a figure.

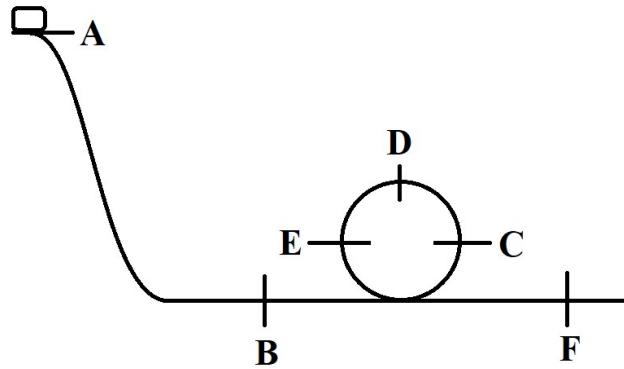
b. What is the initial potential energy of the spring?

c. What is the kinetic energy of the block after it leaves the spring?

d. What is the final speed of the block after it leaves the spring?

e. After some distance the block moves through a rough surface with a coefficient of friction $\mu = 0.05$. What is the total distance the block travels along the rough surface?

10. A 425 kg roller coaster begins from rest at a height $h_1 = 140$ m above the surface of the Earth. The roller coaster makes a circular loop with a radius of $r = 24$ m.



- a. Determine the total energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.
- b. Determine the gravitational potential energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

c. Determine the kinetic energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

d. Determine the speed of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

Name: _____

Class: _____

Due Date: _____

A.4 Rigid Body Mechanics

Additional HL Understandings

- The torque τ of a force about an axis as given by $\tau = Fr \sin \theta$.
- Bodies in rotational equilibrium have a resultant torque of zero.
- An unbalanced torque applied to an extended, rigid body will cause angular acceleration.
- The rotation of a body can be described in terms of angular displacement, angular velocity, and angular acceleration.
- Equations of motion for uniform angular acceleration can be used to predict the body's angular position θ , angular displacement $\Delta\theta$, angular speed ω , and angular acceleration α as given by
 - $\Delta\theta = \frac{\omega_f + \omega_i}{2} t$
 - $\omega_f = \omega_i + \alpha t$
 - $\Delta\theta = \omega_i t + \frac{1}{2} \alpha t^2$
 - $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$
- The moment of inertia I depends on the distribution of mass of an extended body about an axis of rotation.
- The moment of inertia for a system of point masses as given by $I = \sum mr^2$.
- Newton's second law for rotation as given by $\tau = I\alpha$ where τ is the average torque.
- An extended body rotating with an angular speed has an angular momentum L as given by $L = I\omega$.
- Angular momentum remains constant unless the body is acted upon by a resultant torque.
- The action of a resultant torque constitutes an angular impulse ΔL as given by $\Delta L = \tau\Delta t = \Delta(I\omega)$
- The kinetic energy of rotational motion as given by $E_k = \frac{1}{2} I\omega^2 = \frac{L^2}{2I}$.

Additional HL Equations

$$\tau = Fr \sin \theta$$

$$\Delta\theta = \frac{\omega_f + \omega_i}{2} t$$

$$\omega_f = \omega_i + \alpha t$$

$$\Delta\theta = \omega_i t + \frac{1}{2} \alpha t^2$$

$$\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$$

$$I = \sum mr^2$$

$$\tau = I\alpha$$

$$L = I\omega$$

$$\Delta L = \tau\Delta t$$

$$\Delta L = \Delta(I\omega)$$

$$E_k = \frac{1}{2} I \omega^2 = \frac{L^2}{2I}$$

The solutions can be found on the YouTube channel Go Physics Go:

<https://www.youtube.com/@gophysicsgo/playlists>

1. Define, state the equation, and give the units of *angular position* θ .
2. Define, state the equation, and give the units of *angular speed* ω .
3. Define, state the equation, and give the units of *angular acceleration* α .
4. Convert the *suvat* equations from linear motion to circular motion.

5. Define, state the equation, define each variable, and give the units for the *moment of inertia* I . What is the *moment of inertia* I equivalent to in translational motion?

6. Define, state the equation, define each variable, and give the units for *torque*.

7. State the equations for *Newton's second law of motion for linear motion* and *Newton's second law of motion for rotational motion*.

8. Define and state the conditions for *translational equilibrium* and *rotational equilibrium*.

9. State the equations for *power for linear motion* and *power for rotational motion*.

10. State the equations for *linear momentum* and *angular momentum*. Also state the equations for *linear impulse* and *angular impulse*.

11. State the equations for *translational kinetic energy* and *rotational kinetic energy*.

12. State the *law of conservation of linear momentum* and the *law of conservation of angular momentum*. Also state their equations.

13. A solid chocolate sphere with a mass of 9 kg and a diameter of 80 cm is placed on top of a rough incline ($\mu = 0.7$) with a length of 6 m at an angle of 50 degrees. The solid chocolate sphere begins from rest and rolls down the incline.

- a. Draw a figure.

- b. What is the initial height of the solid chocolate sphere?

- c. How many revolutions will it take for the solid chocolate sphere to reach the bottom of the incline?

- d. What will be the final linear speed of the solid chocolate sphere at the bottom of the incline?

- e. What will be the final angular speed of the solid chocolate sphere at the bottom of the incline?

- f. What will be the angular acceleration of the solid chocolate sphere?

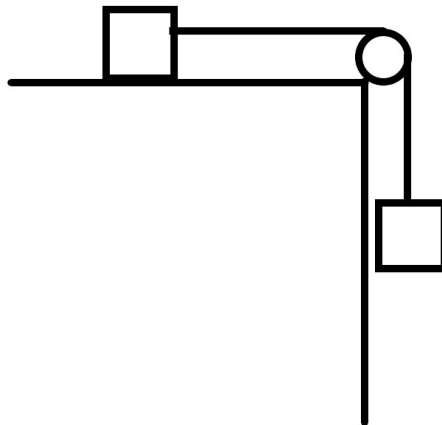
- g. What will be the linear acceleration of the solid chocolate sphere?

- h. How long will it take for the solid chocolate sphere to reach the bottom of the incline?

14. A solid chocolate sphere with a mass of 8 kg and a diameter of 70 cm is rolling to the right on a frictionless horizontal surface with a linear speed of 6 m/s. The surface then becomes rough with a coefficient of dynamic friction of 0.15.
- Draw a figure.
 - What is the angular speed of the solid chocolate sphere as it rolls along the frictionless horizontal surface?
 - What is the angular acceleration of the solid chocolate sphere as it travels along the rough surface?
 - What is the linear acceleration of the solid chocolate sphere as it travels along the rough surface?
 - How many revolutions does the solid chocolate sphere complete as it travels along the rough surface?

- f. How long does it take for the solid chocolate sphere to stop along the rough horizontal surface?

15. A block of mass $m_1 = 7$ kg sits at rest on a horizontal surface with $\mu = 0.2$. Mass m_1 is attached to a massless string which is wrapped around a pulley. Another massless string is wrapped around the same pulley and is holding another block of mass $m_2 = 47$ kg in the air. The pulley is a cylinder which has a mass of $m_C = 12$ kg and diameter of 10 cm.



- a. Draw a free body diagram.

- b. What is the common linear acceleration of the system?
- c. What is the force of tension on the two massless strings?

16. A thin disk with a mass of 250 g and diameter of 40 cm is spinning with an angular speed of 3 rad/sec. A point mass with a mass of 350 g strikes and sticks to the top of the thin disk 4 cm from the edge. What is the final angular speed of the system?



17. A ladder has a mass of 20 kg and is 6 m long is leaning against a frictionless wall. The ladder is at rest and makes an angle of 30 degrees from the wall. Draw a figure and write down the equations for static equilibrium.

18. Write down the common terms and equations for rigid body mechanics.

Name: _____

Class: _____

Due Date: _____

A.5 Galilean and Special Relativity

Additional HL Understandings

- Reference frames.
- Newton's laws of motion are the same in all inertial reference frames and this is known as Galilean relativity.
- In Galilean relativity the position x' and time t' of an event are given by $x' = x - vt$ and $t' = t$.
- Galilean transformation equations lead to the velocity addition equation as given by $u' = u - v$.
- Two postulates of special relativity.
- The postulates of special relativity lead to the Lorentz transformation equations for the coordinates of an event in two inertial reference frames as given by

$$x' = \gamma(x - vt)$$

$$t' = \gamma\left(t - \frac{vx}{c^2}\right)$$
 where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$.
- Lorentz transformation equations lead to the relativistic velocity addition equation as given by $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$.
- The space-time interval Δs between two events is an invariant quantity as given by $(\Delta s)^2 = (c\Delta t)^2 - \Delta x^2$.
- Proper time interval and proper length.
- Time dilation as given by $\Delta t = \gamma\Delta t_0$.
- Length contraction as given by $L = \frac{L_0}{\gamma}$.
- The relativity of simultaneity.
- Space-time diagrams.
- The angle between the world line of a moving particle and the time axis on a space-time diagram is related to the particle's speed as given by $\tan \theta = \frac{v}{c}$.
- Muon decay experiments provide experimental evidence for time dilation and length contraction.

Additional HL Equations

$$x' = x - vt$$

$$t' = t$$

$$u' = u - v$$

$$x' = \gamma(x - vt) \text{ where } \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t' = \gamma \left(t - \frac{vx}{c^2} \right)$$

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$$

$$(\Delta s)^2 = (c\Delta t)^2 - \Delta x^2$$

$$\Delta t = \gamma \Delta t_0$$

$$L = \frac{L_0}{\gamma}$$

$$\tan \theta = \frac{v}{c}$$

The solutions can be found on the YouTube channel Go Physics Go:

<https://www.youtube.com/@gophysicsgo/playlists>

1. Define *observer*.
2. Define *reference frame*.
3. Define *inertial reference frame*.
4. Define *event*.
5. Define *simultaneous events*.
6. Define and state the equations for *Galilean transformations*.

7. Define *Galilean relativity*.
8. State *the two postulates of relativity*.
9. A train is traveling horizontally to the right with a speed of $18 \frac{\text{m}}{\text{s}}$. A man on the train is walking to the right with a speed of $+4 \frac{\text{m}}{\text{s}}$. Determine the velocity of the man by an observer at rest outside the train.
10. Usain Bolt and Florence Griffith-Joyner race each other. They both begin at the same time. Usain Bolt runs with a constant speed of $10.44 \frac{\text{m}}{\text{s}}$ while Florence Griffith-Joyner runs with a constant speed of $9.53 \frac{\text{m}}{\text{s}}$.
- What is the distance between Usain Bolt and the starting line after two minutes?
 - According to Florence Griffith-Joyner, what is the distance to Usain Bolt after two minutes?
 - Determine the speed of Usain Bolt as observed by Florence Griffith-Joyner.

11. What is the conclusion of the Michelson-Morley experiment?

12. State the *Lorentz transformation equations*. Define each variable.

13. State and draw a *Lorentz factor vs. speed* graph.
14. An event occurs at position $x = 4,000$ m and time $t = 6.0$ s. Where and when did the event occur according to a rocket traveling horizontally in the positive direction at a speed of $v = 0.4c$? The origins of both reference frames are zero when both clocks read zero.
15. A rocket moves to the right past an IB school with a speed of $0.6c$. The IB school is located at the origin. Determine the time reading of the rocket if $x = 300$ m. The origins of both reference frames are zero when both clocks read zero.

16. Describe *time dilation* and *proper time interval*.

17. Describe *length contraction* and *proper length*.

18. Describe the *twin paradox*.
19. A man at rest sees two objects traveling towards each other each with a speed of $0.5c$. What is the speed of one object as seen by the other object? What would this value be using classical physics?
20. Romeo is behind Juliet and is running towards her with a speed of $0.6c$ as seen by a man at rest. Juliet is running away from Romeo with a speed of $0.4c$ as seen by the same man at rest. What is the speed of Romeo as observed by Juliet? What would this value be using classical physics?
21. A rocket is moving in a straight line with a constant speed v in space. It sends out a pulse of light ahead of it. How fast does the pulse of light move relative to an observer at rest on Earth?

22. A rocket at rest on Earth is measured to have a length of 45.0 meters and a diameter of 5.60 meters. The rocket is then launched toward Alpha Centauri, which is 4.3 light years from the Earth, at $2.2 \times 10^8 \frac{\text{m}}{\text{s}}$.
- What will be the length of this rocket as measured by an observer on the Earth?
 - What will be the length of the rocket as measured by an astronaut on board the rocket?
 - What will be the diameter of the rocket as measured by an observer on the Earth?
 - What will be the distance to Alpha Centauri as measured by the astronaut on board the rocket?
23. The distance to the star Epsilon Indi, as measured from the Earth frame of reference, is 1.07×10^{17} m.
- What is this distance in light years?
 - What will be the distance in light years to Epsilon Indi as measured by an observer on a rocket heading toward this star at 85% of the speed of light?
 - How long in years will it take for this rocket to reach Epsilon Indi according to an observer on the Earth?

24. A rocket is moving toward the star Sirius with a velocity of $2.955 \times 10^8 \frac{\text{m}}{\text{s}}$. The distance to Sirius as measured from the rest frame on Earth is measured to be 8.14×10^{16} m.
- What will be the velocity of this rocket as a decimal fraction of the speed of light?
 - What is the distance to Sirius in light years?
 - What will be the distance to Sirius as measured by an astronaut on board the rocket?
25. As measured from the Earth the distance to Tau Ceti is determined to be 11.8 light years. How fast in $\frac{\text{m}}{\text{s}}$ must a rocket be moving toward Tau Ceti so that the distance to Tau Ceti is reduced to 1.18 light years?
26. How fast must a rocket be moving in order for its length to be reduced to 1.0% of its rest length?
27. According to an observer on the Earth the time it should take to reach a certain star is determined to be 7.50 years. How long will it take to reach this star according to an observer on board a rocket moving toward this star with a velocity of $0.985c$?

28. The distance to Barnard's star is measured to be 6.00 ly by an observer at rest on the Earth.
- Assuming that a rocket is moving toward this star at $0.98c$, how long in years will it take for this rocket to reach Barnard's star according to an observer on the Earth?
 - How long in years will it take to reach this star according to an observer on board the rocket?
 - What will be the distance in light years to Barnard's star according to an observer on board the rocket?
 - Assuming that the astronaut was 21 years old when she left the Earth in 1988, in what year will the astronaut arrive at Barnard's star according to an observer on Earth?
 - How old will the astronaut be when she arrives at Barnard's star according to an observer on board the rocket?
 - Suppose that the astronaut has a normal heart rate of 65 beats per minute when measured while at rest on the Earth. What will be the astronaut's heart rate as monitored by an observer on board the rocket with the astronaut?
 - What will the astronaut's heart rate be while on the rocket moving toward Barnard's star as monitored by an observer on the Earth?

29. Two astronauts play a game of chess on a rocket moving with a velocity of $0.999c$ away from the Earth. According to the astronauts the game takes 2.5 hours. How long does the game take according to an observer at rest on Earth?
30. A rocket is moving toward Epsilon Eridani, which is 11.3 ly away as measured by an observer at rest on the Earth, at $0.998c$. When the astronaut leaves the Earth in 1991 he has just had his 22nd birthday and his young daughter has just turned 1.0 years old. The rocket travels to the star, remains 6.0 months and then returns to the Earth at the same speed.
- In what year will the rocket return to the Earth?
 - How many years will the journey take according to the astronaut on board the rocket?
 - How old will the astronaut be when he returns to the Earth?
 - How old will his daughter be when he returns to the Earth?
31. Two twins are 22.0 years old when one of them sets out on a journey through space with a constant speed. The twin in the spaceship measures time with an accurate watch. When he returns to Earth, he claims to be 28.0 years old while the twin left on Earth is 40.0 years old. What was the speed of the spaceship?

32. A neutron outside the confines of the nucleus of an atom is unstable and has a life expectancy (half-life) of 6.0 minutes. Suppose that a fast moving alpha particle collides with a block of beryllium and knocks a neutron out of the nucleus with a speed of $8.15 \times 10^7 \frac{\text{m}}{\text{s}}$. What will be the expected lifetime of this neutron as measured by an observer in the rest frame?
33. Describe the equation of the *space-time interval* Δs . Describe *proper time interval* and *proper length* in terms of the *space-time interval* Δs .

34. Describe the *relativity of simultaneity*.

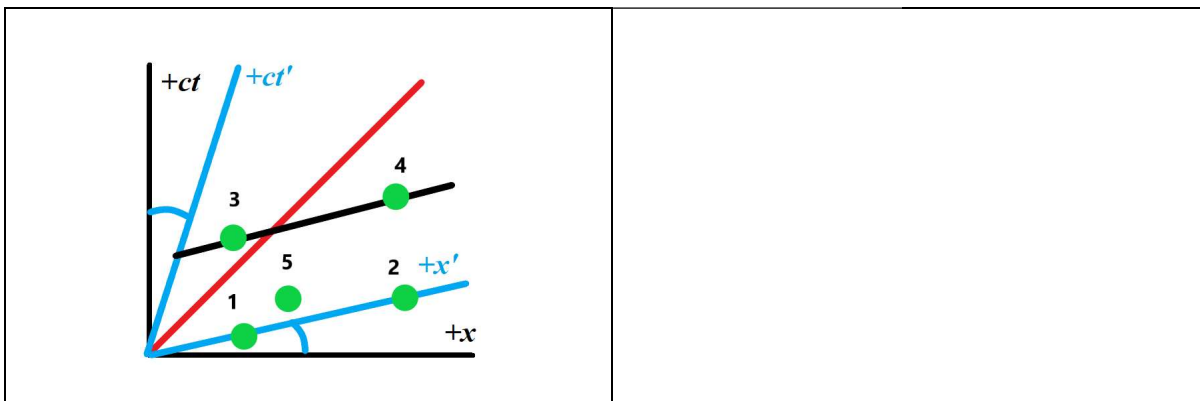
35. Draw and label the axes of a space-time diagram.
36. Draw a space-time graph where two events occur at the same time and another space-time graph where two events which occur at the same location.
37. Define the *world line*. Draw a *world line* in a space-time graph of an object at rest, a second object moving with a velocity of $0.4c$, and a third object moving with a velocity of $0.8c$.

38. Describe the relationship between the angle between the world line of a moving particle and the time axis on a space-time diagram.

39. Add another reference frame to a space-time diagram. On the space time diagram label an event and describe how that event takes place at two different times in both reference frames.

40. Draw a diagram with two reference frames. Label four stationary events in an (x', ct') graph. Draw a second diagram with two reference frames. Label four events which occur at the same time in an (x', ct') graph.

41. Below is a space-time diagram with two reference frames and five events. Determine the order of events according to the (x, ct) graph and the (x', ct') graph.



42. Draw and describe a graph of $\Delta s^2 = -1$.

43. Draw and describe a graph of $\Delta s^2 = +1$.

44. Three observers L , M , and R are separated a distance A from each other on a parallel line. They all travel from rest to a speed of $0.4c$ to the right and remain a distance A from each other. The observer in the middle M sends out a light pulse in all directions. The light gets reflected from observer L and observer R and returns to M . Does observer M receive the light pulse from observer L or observer R first?

45. Describe *muon decay*.