DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
AP PHYSICS

LSN 8-1: ANGULAR QUANTITIES
LSN 8-2: CONSTANT ANGULAR ACCELERATION
LSN 8-3: ROLLING MOTION (WITHOUT SLIPPING)

Big Idea(s):

- Big Idea 3: The interactions of an object with other objects can be described by forces.
- Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding(s):

- A force exerted on an object can cause a torque on that object.
- A net torque exerted on a system by other objects or systems will change the angular momentum of the system.

Essential Knowledge(s):

- Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.
  - The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.
  - The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.
  - The net torque on a balanced system is zero.

Essential Knowledge(s):

- The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.
  - Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.
  - Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.
  - The angular acceleration of an object or rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.

Essential Knowledge(s):

- A torque exerted on an object can change the angular momentum of an object.
  - Angular momentum is a vector quantity, with its direction determined by a right-hand rule.
  - The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.

Essential Knowledge(s):

- A torque exerted on an object can change the angular momentum of an object.
  - The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity.
  - The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.

Essential Knowledge(s):

- Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis.

Learning Objective(s):

- The student is able to use representations of the relationship between force and torque.
- The student is able to compare the torques on an object caused by various forces.
- The student is able to estimate the torque on an object caused by various forces in comparison to other situations.

Learning Objective(s):

- The student is able to design an experiment and analyze data testing a question about torques in a balanced rigid system.
- The student is able to calculate torques on a two-dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction).

Learning Objective(s):

- The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis.
- The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis.

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- The student is able to predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum.
- In an unfamiliar context or using representations beyond equations, the student is able to justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object.

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- The student is able to plan data collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object.
- The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system.

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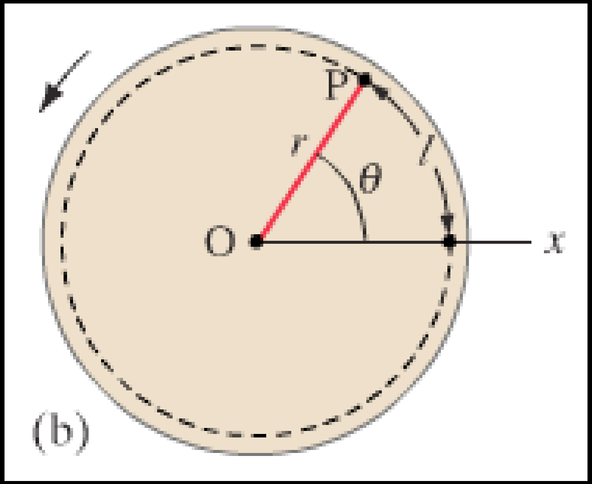
- The student is able to plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data.

Rigid Objects Only

- An object with a definite shape that doesn’t change
- Deformations not considered
- Vibration not considered
- *Ideal* rigid objects

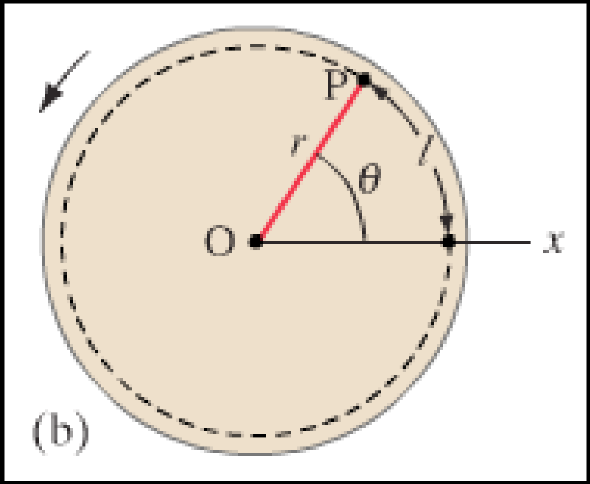
Overview of Rotational Equations of Motion

Angular Quantities



- Think of a wheel
  - All points rotate about the center, also called the ***axis of rotation***
  - A line drawn from the center to any point on the edge is a ***radius***
  - During uniform rotational motion, a radius will sweep out the same angle θ in the same amount of time at any point on the circle

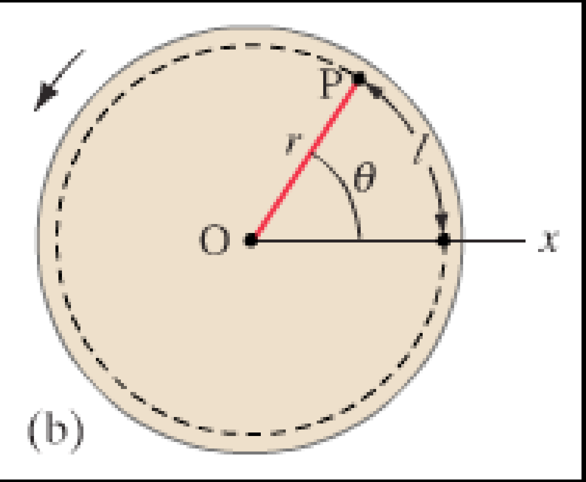
Angular Quantities



- Radians
  - Radians are angle measurements similar to degrees but use 2π to define a full circle instead of 360°
  - One radian is the angle θ subtended by an arc *l* is equal to the radius *r*
  - In the above diagram, OP = *l*
  - Any angle (in radians) can be found by taking the arc length and dividing by the radius

$$\theta = \frac{l}{r}$$

Angular Quantities



- Radians
  - Since there are 2π radians in a circle, we can derive an expression for the circumference for a circle
  - We can also see that 360° = 2π rad and so one revolution = 2π rad

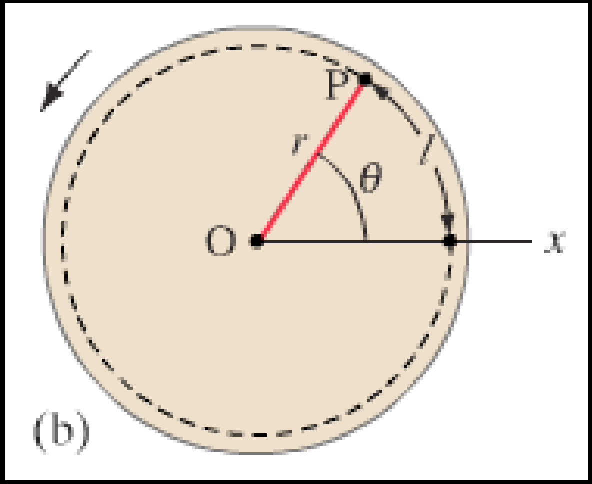
$$\theta = \frac{l}{r}$$

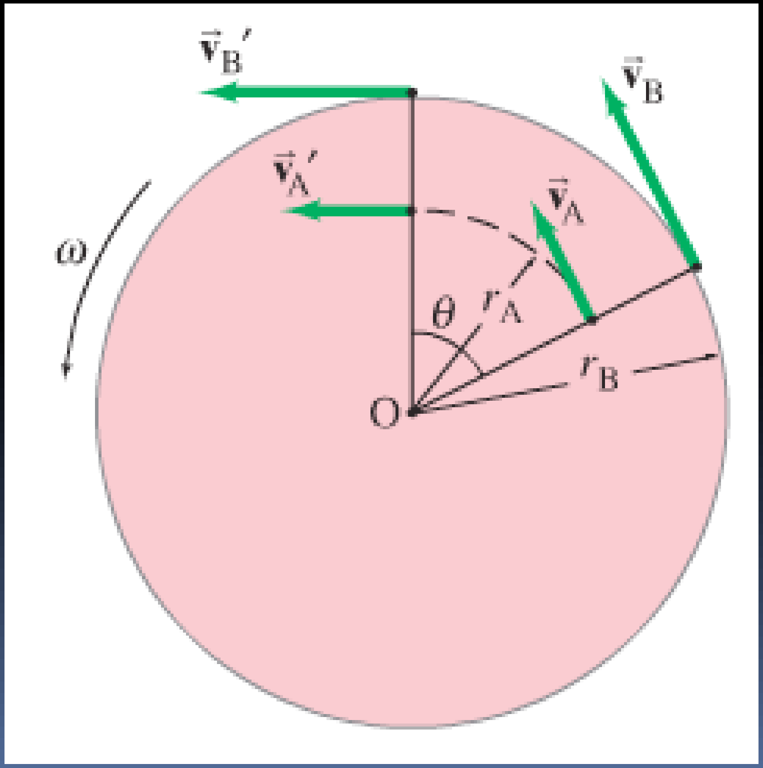
$$\theta r = l$$

$$Circumference = l = 2\pi r$$

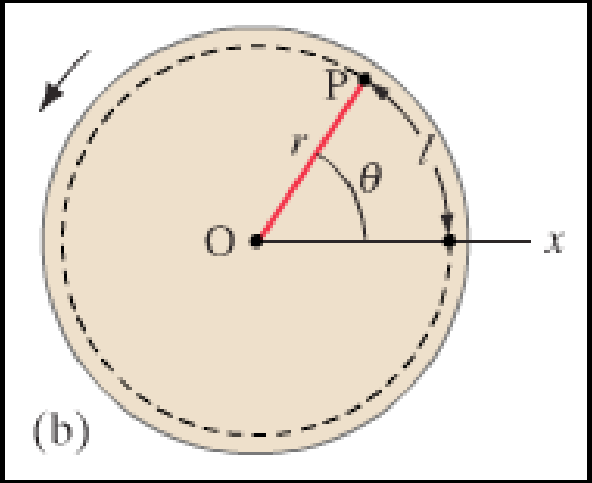
Angular Quantities

- Rotational Motion
  - ***Rotational motion*** refers to movement of the body as a whole
  - All points on the body will have the same ***angular velocity*** and ***angular acceleration***

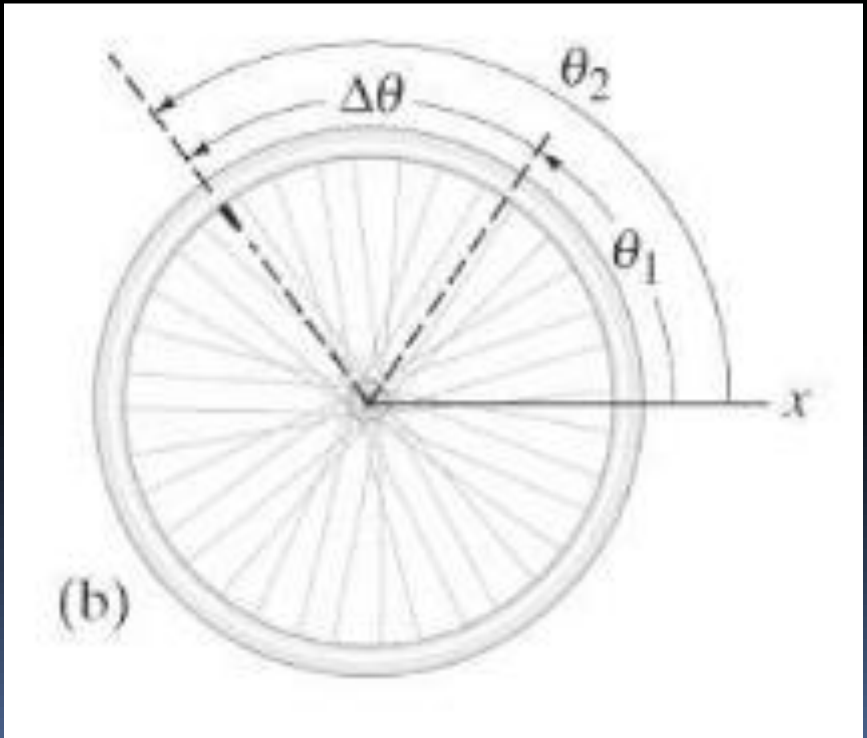




Angular Quantities

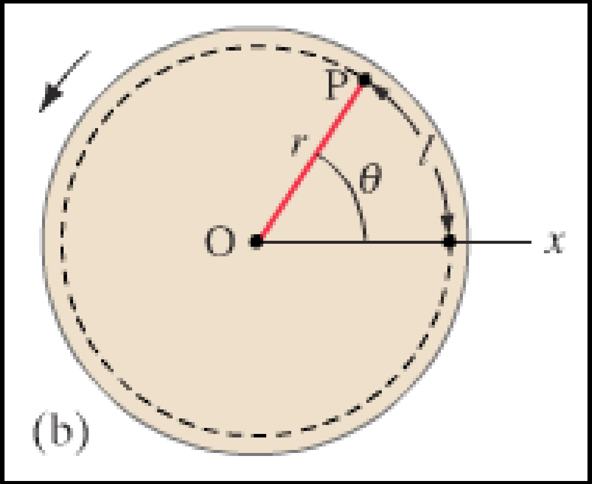


- Angular Displacement
  - From a reference point *x*, a body rotates some angle θ_1 and then to another angle θ_2.
  - ***Angular displacement*** is defined as the change in angles, $\Delta\theta$



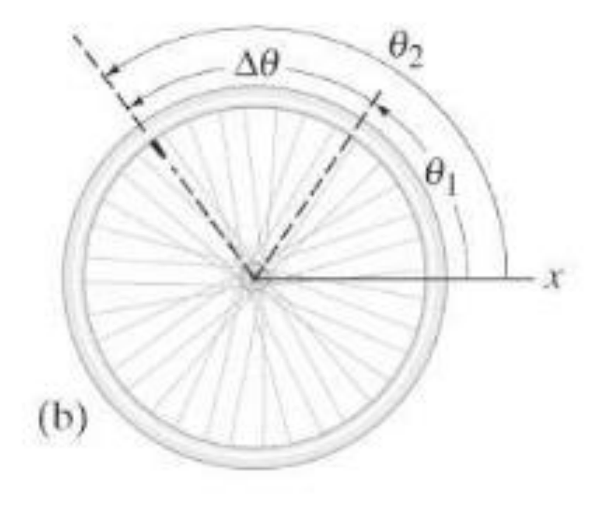
$$\Delta\theta = \theta_2 - \theta_1$$

Angular Quantities

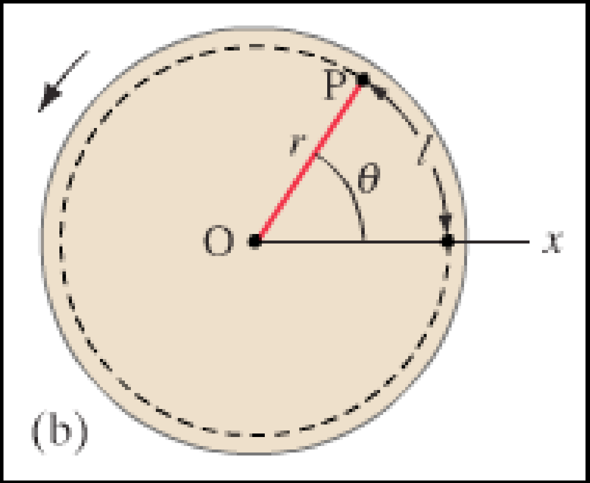


- Angular Velocity
  - Velocity in both linear and rotational motion is the change in displacement divided by the change in time
  - ***Average angular velocity, ω,*** is defined as the change in angular displacement, Δθ, divided by time

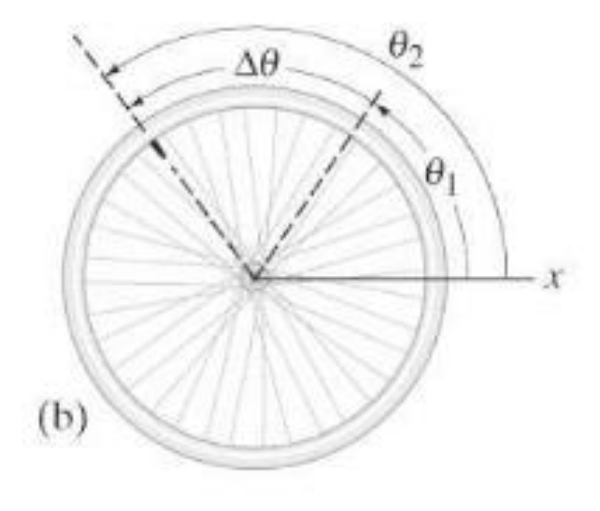
$$\overline{\omega} = \frac{\Delta\theta}{\Delta t}$$



Angular Quantities



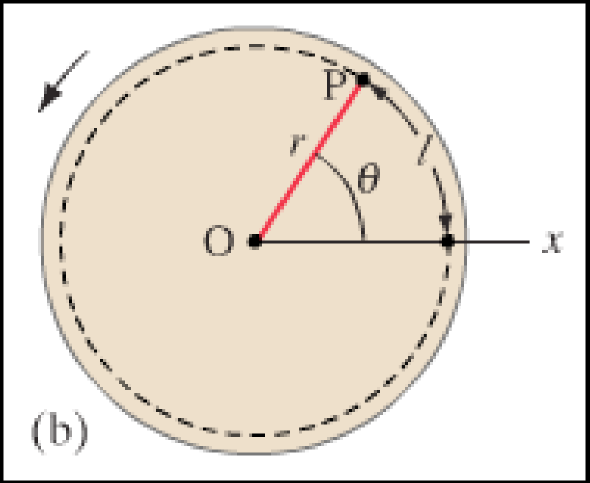
- Angular Velocity
  - ***Instantaneous angular velocity, ω,*** is defined as the change in angular displacement, Δθ, divided by time ***as the change in time approaches zero***



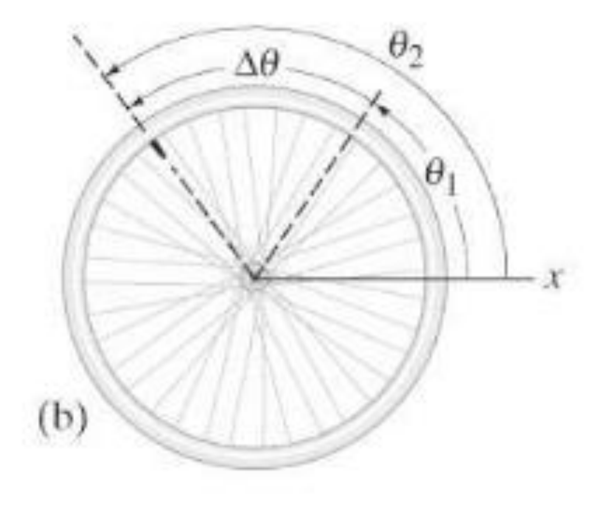
$$\omega = \lim_{\Delta t \to 0} \frac{\Delta \theta}{\Delta t}$$

Similar to average and instantaneous linear velocity

Angular Quantities



- Angular Acceleration
  - Acceleration in both linear and rotational motion is the change in velocity divided by the change in time
  - ***Average angular acceleration, α,*** is defined as the change in angular velocity, Δω, divided by time

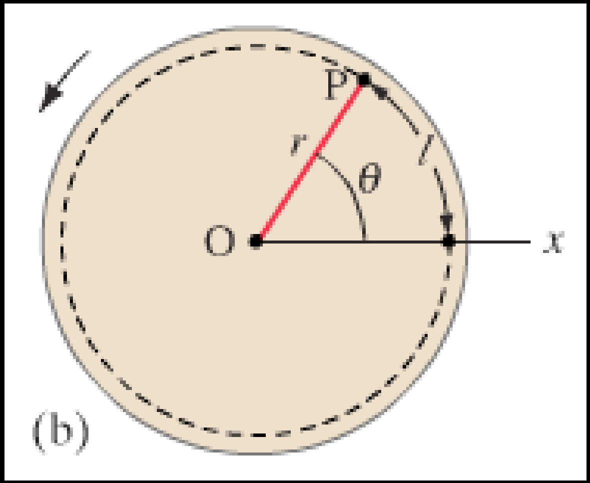


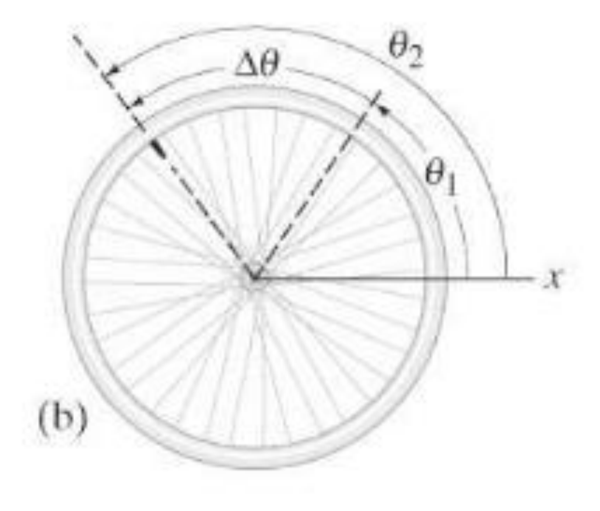
$$\overline{\alpha} = \frac{\Delta\omega}{\Delta t} = \frac{\omega_2 - \omega_1}{\Delta t}$$

Angular Quantities

- Angular Acceleration
  - ***Instantaneous angular acceleration, α,*** is defined as the change in angular velocity, Δω, divided by time ***as the change in time approaches zero***

$$\alpha = \lim_{\Delta t \to 0} \frac{\Delta\omega}{\Delta t}$$

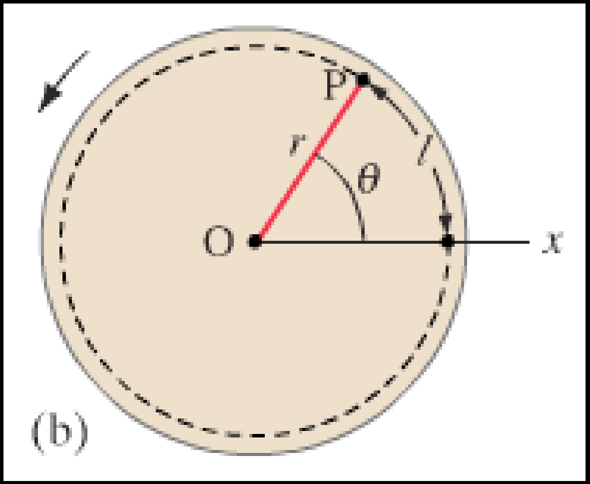


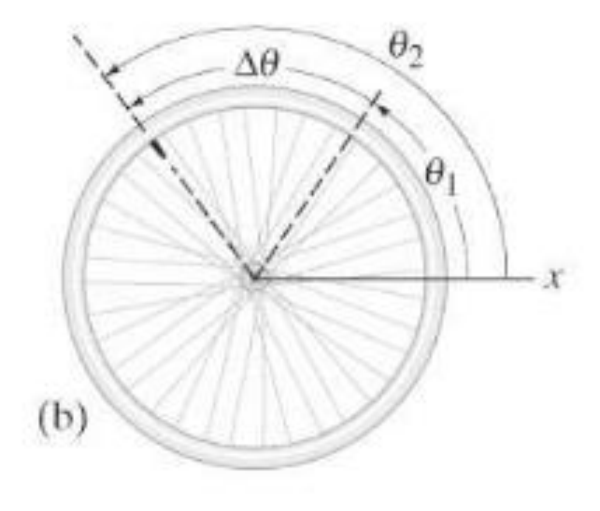


Similar to average and instantaneous linear acceleration

Angular Quantities

- Units
  - The units for angular velocity are radians/second (rad/s)
  - The units for angular acceleration are radians/seconds squared (rad/s²)

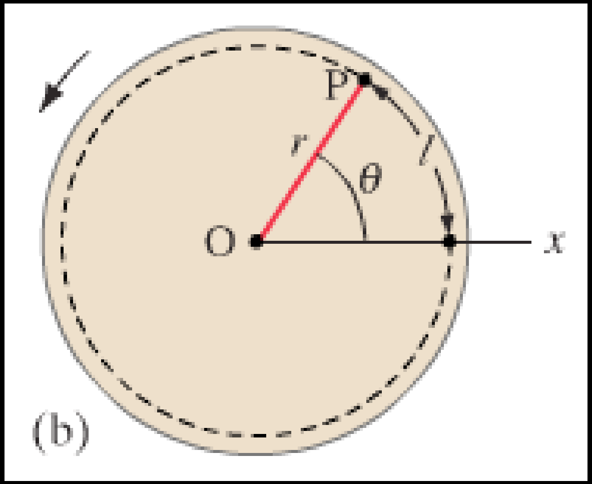


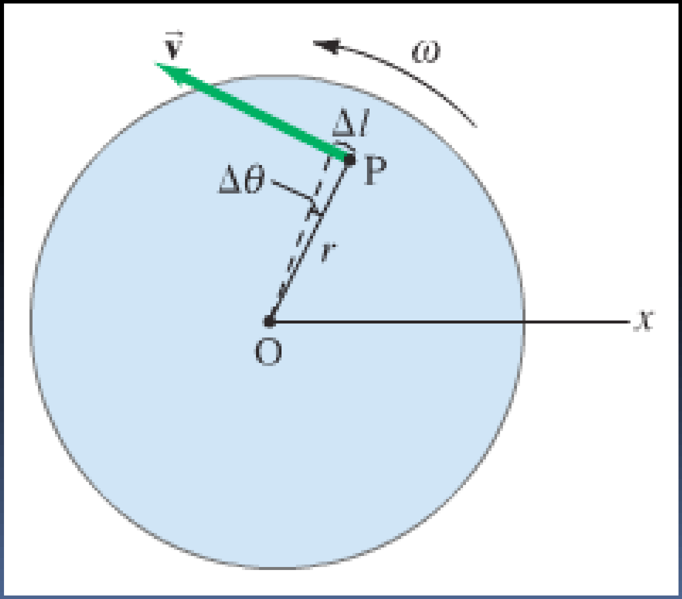


Similar to average and instantaneous linear acceleration

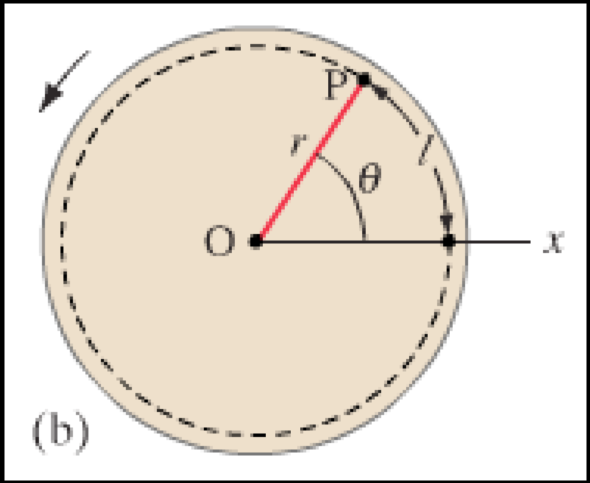
Linear Quantities

- While the angular velocity and angular acceleration are the same for all points on a rotating object, the same is not true for the linear velocity and linear acceleration of all points





Linear Quantities



- Linear Velocity
  - Consider the linear velocity of some point P which is a distance r from the axis of rotation

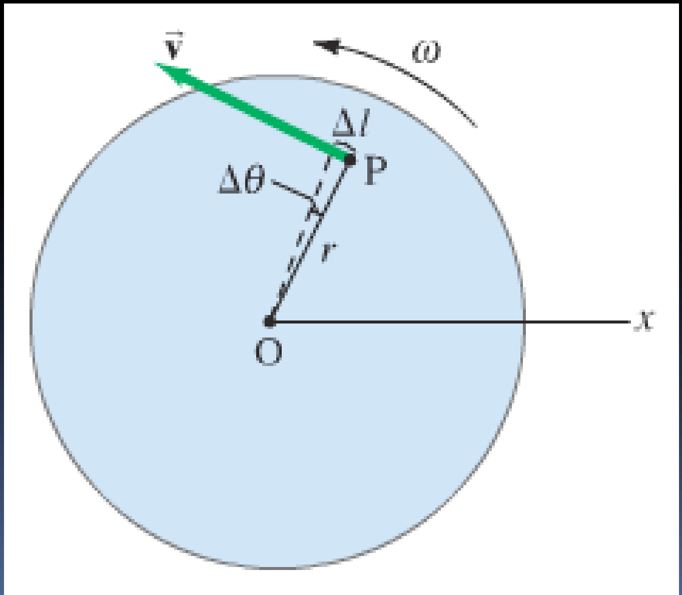
$$v = \frac{\Delta l}{\Delta t}$$

$$\Delta l = r\Delta\theta$$

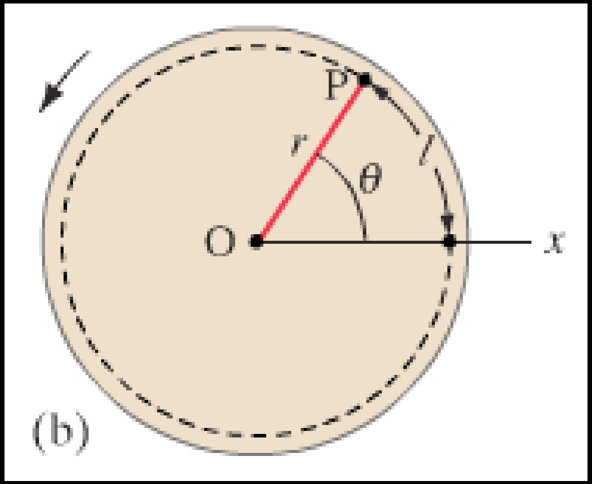
$$v = \frac{r\Delta\theta}{\Delta t}$$

$$\omega = \frac{\Delta\theta}{\Delta t}$$

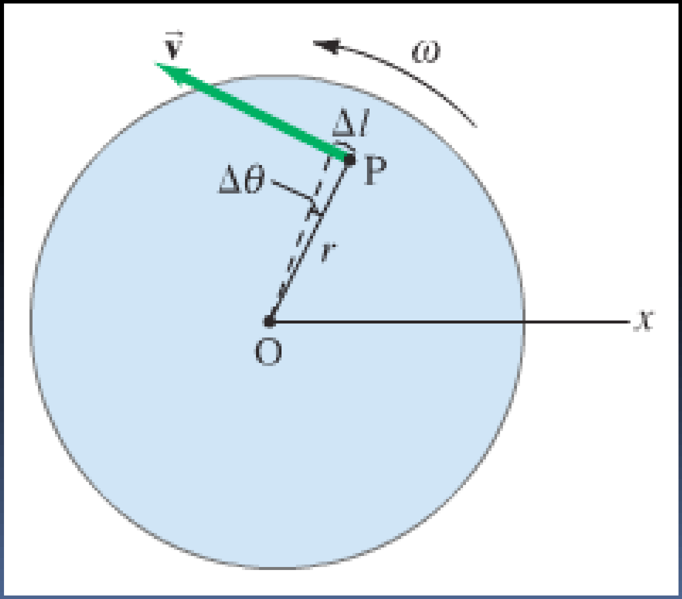
$$v = r\omega$$



Linear Quantities



- Linear Velocity
  - While angular velocity, ω, is a constant, linear velocity changes as a function of distance from the center
  - The further from the center, the higher your linear velocity



$$v = r\omega$$

Linear Quantities

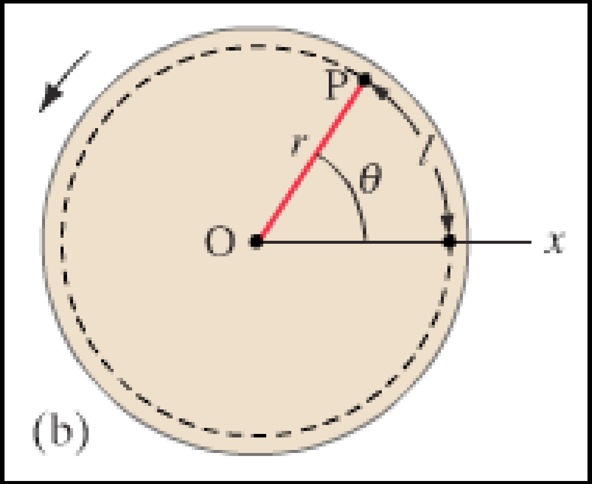
- Tangential Acceleration

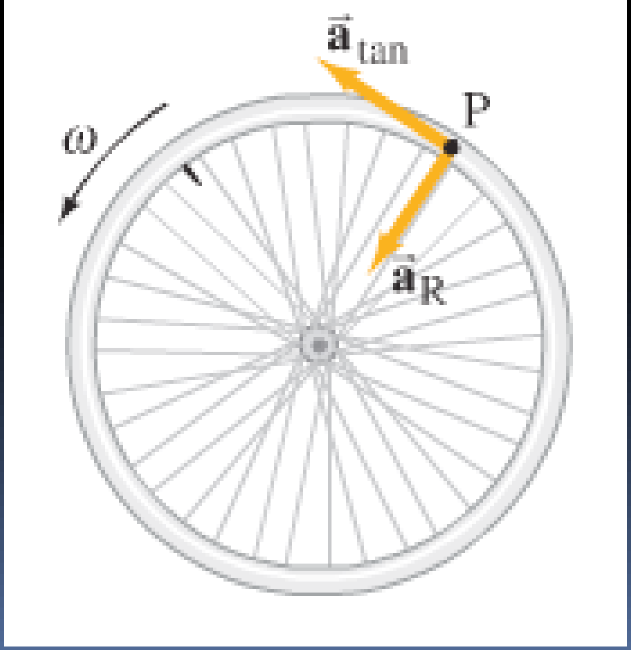
$$a_{\tan} = \frac{\Delta v}{\Delta t}$$

$$v = r\omega$$

$$a_{\tan} = r\frac{\Delta \omega}{\Delta t}$$

$$a_{\tan} = r\alpha$$





Linear Quantities

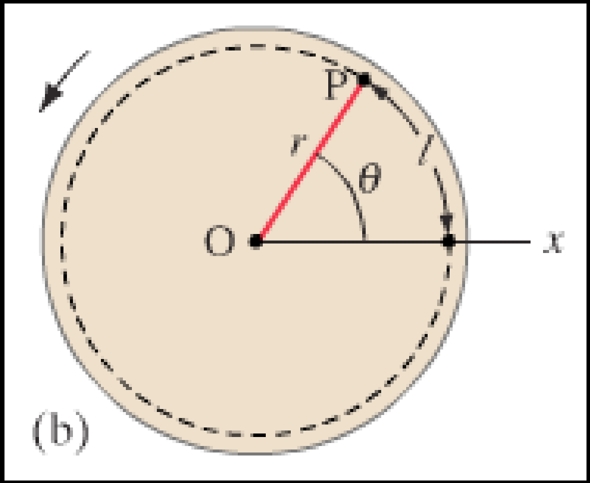
- Centripetal Acceleration

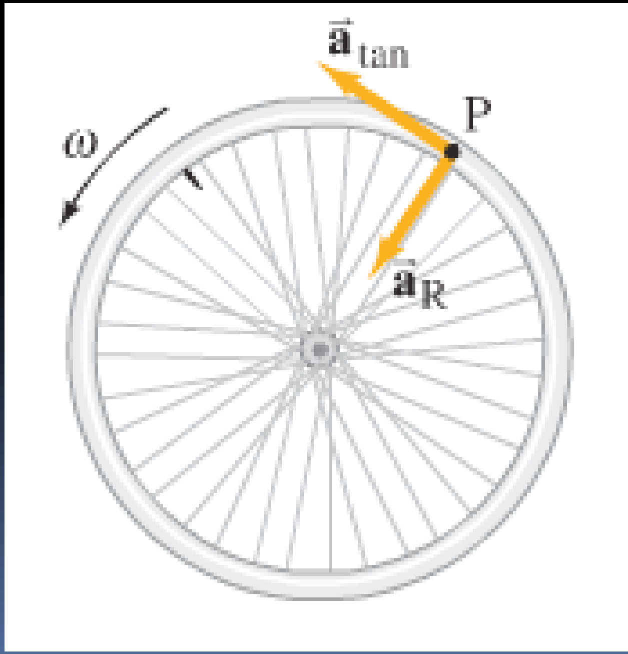
$$a_c = \frac{v^2}{r}$$

$$v = r\omega$$

$$a_c = \frac{(r\omega)^2}{r}$$

$$a_c = r\omega^2$$





Linear and Rotational Quantities - Summary

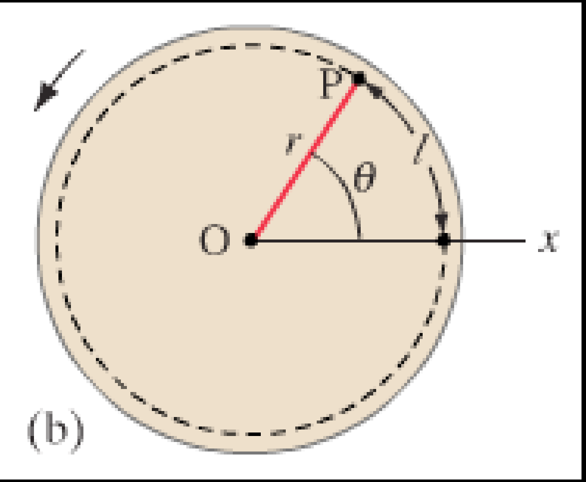


TABLE 8–1 Linear and Rotational Quantities

Linear	Type	Rotational	Relation
x	displacement	θ	$x = r\theta$
v	velocity	ω	$v = r\omega$
$a_{\tan}$	acceleration	α	$a_{\tan} = r\alpha$

More Angular Quantities

- Frequency
  - Frequency is the number of revolutions per second (rev/s)
  - 1 rev/s = 2π rad/s

$$f = \frac{\omega}{2\pi}$$

$$\omega = 2\pi f$$

More Angular Quantities

- Period
  - Period is the time (s) per revolution (s/rev)
  - As such it is the inverse of frequency

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

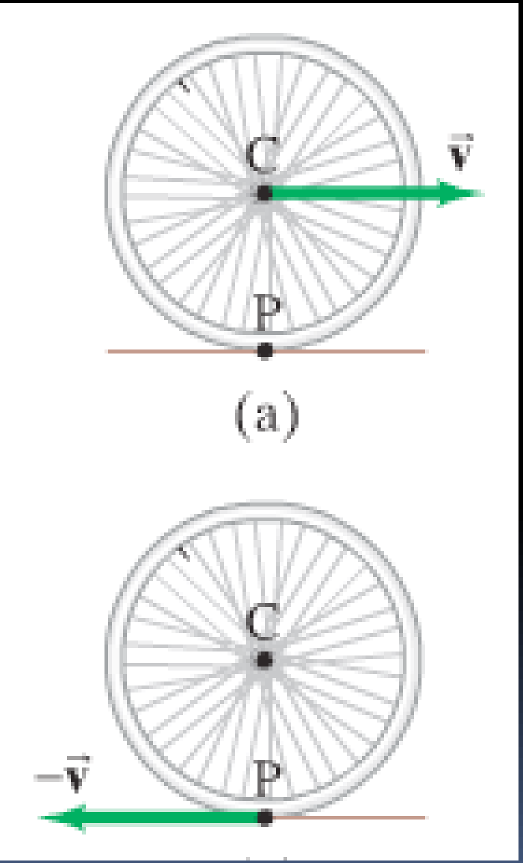
$$T = \frac{1}{f}$$

Constant Angular Acceleration

Angular	Linear			
$\omega = \omega_0 + \alpha t$	$v = v_0 + at$	[constant α, a]	**(8–9a)**	*Kinematic equations*
$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$	$x = v_0 t + \frac{1}{2} a t^2$	[constant α, a]	**(8–9b)**	*for constant*
$\omega^2 = \omega_0^2 + 2\alpha\theta$	$v^2 = v_0^2 + 2ax$	[constant α, a]	**(8–9c)**	*angular acceleration*
$\overline{\omega} = \dfrac{\omega + \omega_0}{2}$	$\overline{v} = \dfrac{v + v_0}{2}$	[constant α, a]	**(8–9d)**	$(x_0 = 0, \theta_0 = 0)$

Rolling Motion (Without Slipping)

- Rolling motion involves translational and rotational motion
- In the diagram, the axis of rotation (C) is exhibiting translational motion
- Meanwhile, all other points on the body of the wheel are exhibiting clockwise rotational motion

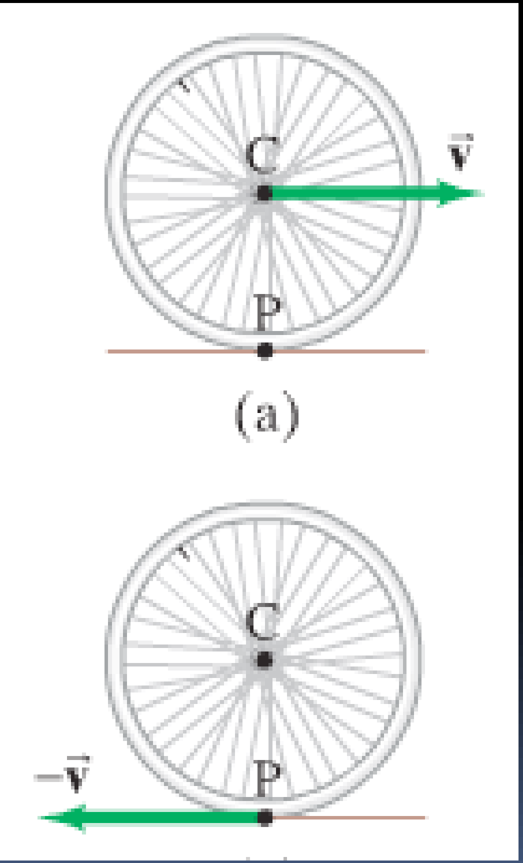


Rolling Motion (Without Slipping)

- The linear speed of the wheel will be

$$v = r\omega$$

- This equation is only valid if there is no slipping of the wheel on the surface
- No slipping depends on a high enough friction force between the wheel and the surface



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Big Idea(s):

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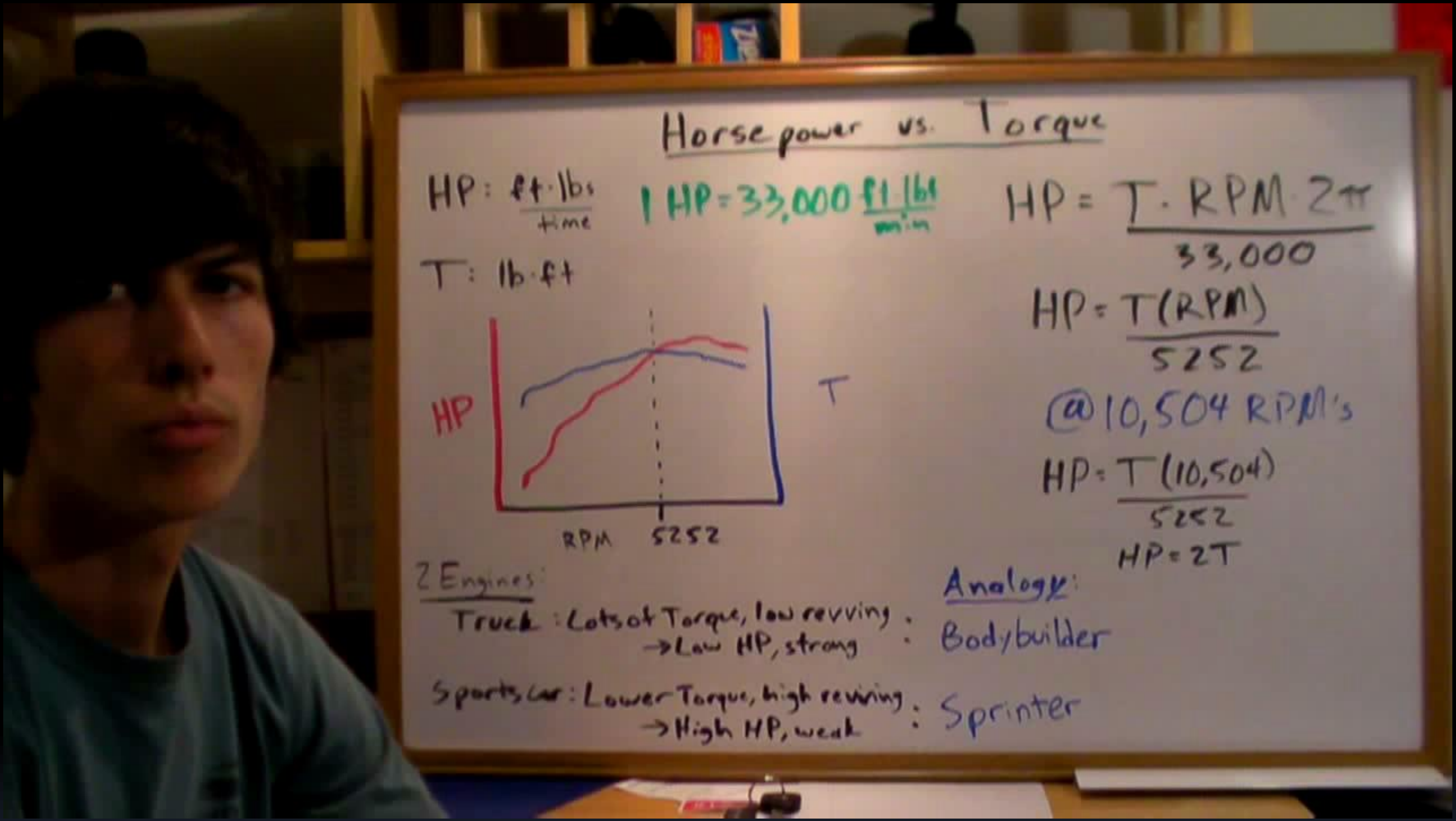
- Big Idea 4: Interactions between systems can result in changes in those systems.

QUESTIONS?

Homework

#1-21



VIDEO:
TORQUE VS. HORSEPOWER