Course announcement

- The homework set 2 has been posted on eLearn. Please submit your homework via eLearn by 5PM, 10/21. No late homework will be accepted.
- The first midterm will on 10/25 (Tuesday). Exam will be started 8:00AM.

4	10/7(Fri.)	**Energy:** kinetic energy and work
5	10/11(Tue.)	**Energy:** potential energy and conservation of energy
5	10/14(Fri.)	**Gravity:** Law of gravity (Homework2)
6	10/18(Tue.)	**Gravity:** Gravitational energy and gravitational field
6	10/21(Fri.)	**Review I**
7	10/25(Tue.)	Mid Term 1

Midterm Exam 1

- Exams will be started at 8:00AM and ends at 9:50AM.
- Please bring student ID and calculator.
- You can bring one A4 information sheet for the exam.
- Cheating will result in 0 points for the whole exam and will be reported to university.

Exams Corrections for Midterm 1

- After you hand in your answer of the exam, you can work out a correction (open book) and hand in on eLearn within 48 hours.
- The correction must be work out by yourself. Copying others' answers will result in 0 points for the exam.
- A fully correct correction of an exam problem will earn 60% of the original scores.
- Taking the higher score of original or correction as the score of each single exam problem. Sum all the scores of the exam problem will be the final score of the exam.

Policy for COVID-19

- We follow university guideline about course under COVID-19.
- Please have facial mask with you
- For students who cannot attend exam due to COVID-19, they can have test remotely with monitor of web camera.

(https://teams.live.com/meet/9570955571789). The problem will be posted on eLearn and can be handed via eLearn. Only students inform me in advance can have test via eLearn.

Problem about Exam

- There will be 6 problem sets. Range: 1~8 chapter of Essential University Physics by Richard Wolfson.
- All the problems will be related to materials covered in class, problem discussed in class, and homework problems.

GENERAL PHYSICS B1 REVIEW

2022/10/21

Dynamics: physical quantities evolving with time

- If the physical quantities that we are interested in are a function of time. The study of how these physical quantities change with time is called dynamics.
- Physical quantities that we are interested in to describe the motion of an object along a straight line:

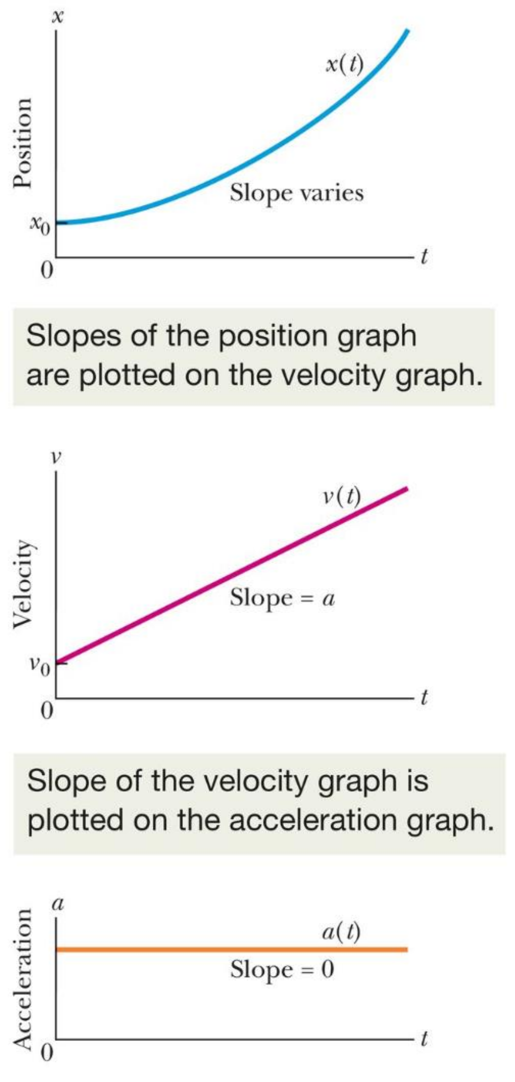
position, velocity, and acceleration

- Position: x_1
- Displacement: $\Delta x = x_2 - x_1$ (a vector)
- Average velocity: $v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$ (a vector)
- Average speed: $S_{avg} = \frac{\text{total distance}}{\Delta t}$ (a scalar)
- Instantaneous velocity: $v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$ (a vector)
- Average acceleration: $a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$ (a vector)
- Instantaneous acceleration : $a = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2 x}{dt^2}$ (a vector)

Constant acceleration motion

- When acceleration is constant, we have:

Equation	Missing Quantity
$v = v_0 + at$	$x - x_0$
$x - x_0 = v_0 t + \frac{1}{2} a t^2$	v
$v^2 = v_0^2 + 2a\left(x - x_0\right)$	t
$x - x_0 = \frac{1}{2}\left(v_0 + v\right) t$	a
$x - x_0 = vt - \frac{1}{2} a t^2$	v_0



1.Safety Distance on a Highway

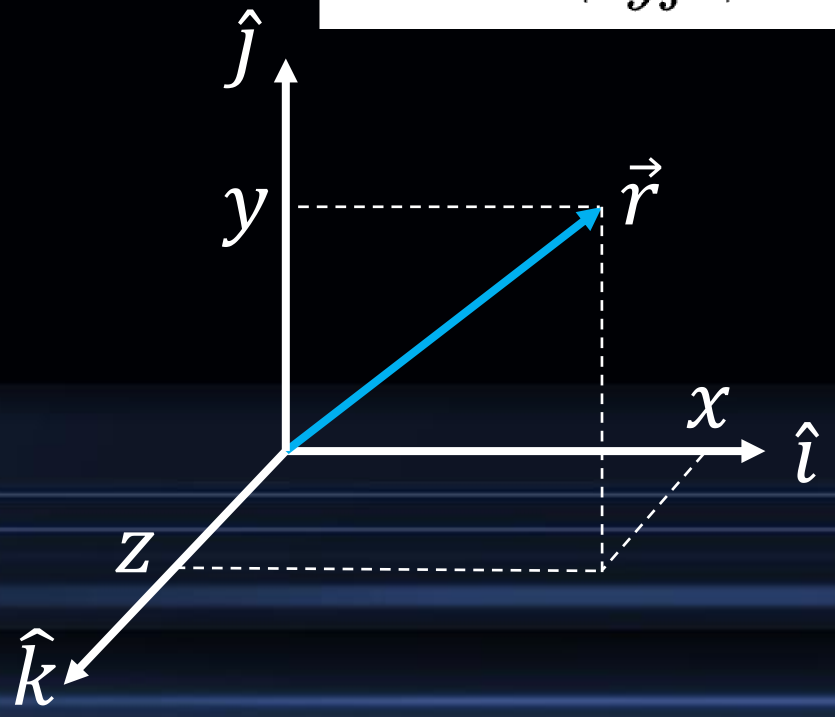
On a dry road, a car with good tires may be able to brake with a constant deceleration of $5m/s^2$. Now a car break down at the middle of a high way. The driver wants to put a warning sign at the back of the car. Assuming other drivers start to brake their car right after passing the warning sign. If the speed limit of the road is $100km/hr$, how far should the driver put the warning sign? (1point)

Solution To be sure other cars have sufficent distance to stop($v_f = 0m/s$), the warning sign need to put at a distance s that the other cars start to decelerate with $a = -5m/s^2$ with initial velocity $v_0 = 100km/hr = 27.8m/s$. We can use the formula $v_f^2 = v_0^2 + 2as$ to find out the distance s. Thus, $s = -\frac{v_0^2}{2a} = 77m$. (For the significant figure, the acceleration only has significant up to integer. Therefore, the significant figure of the answer should also only up to integer.)

Position in two and three dimension

- Position: a vector that extends from a reference point (usually the origin) to the point of interest.

$$\overrightarrow{r} = x\hat{\mathrm{i}} + y\hat{\mathrm{j}} + z\widehat{\mathrm{k}}$$

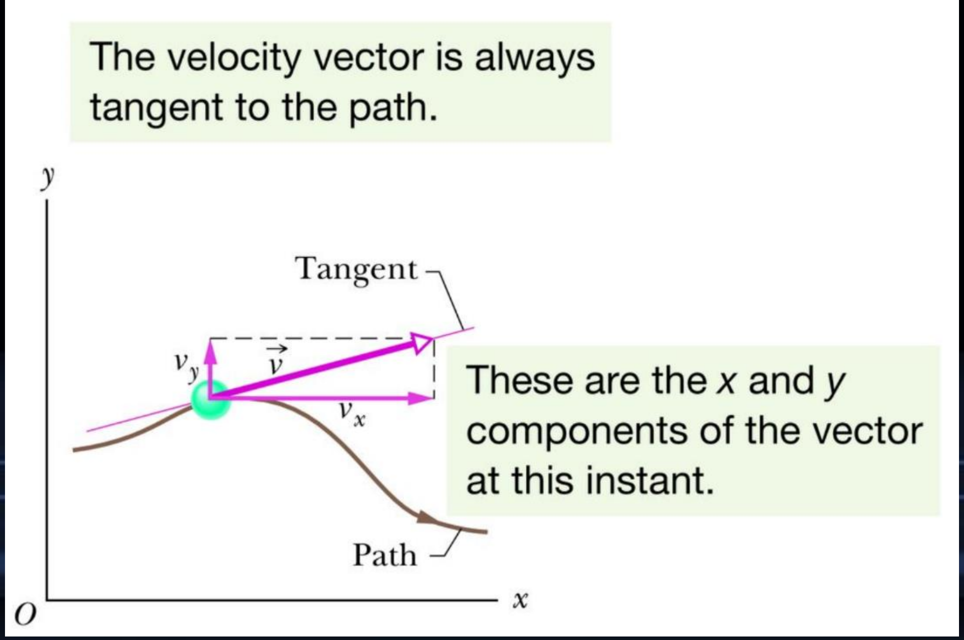


Average velocity and instantaneous velocity

- Instantaneous velocity

$$\vec{v} = \frac{d\vec{r}}{dt}$$

$$\vec{v} = \frac{d}{dt}\left(x\hat{\mathrm{i}} + y\hat{\mathrm{j}} + z\hat{\mathrm{k}}\right) = \frac{dx}{dt}\hat{\mathrm{i}} + \frac{dx}{dt}\hat{\mathrm{j}} + \frac{dz}{dt}\hat{\mathrm{k}}.$$



Average acceleration and instantaneous acceleration

- Average acceleration

$$\overrightarrow{a}_{\text{avg}} = \frac{\overrightarrow{v}_2 - \overrightarrow{v}_1}{\Delta t} = \frac{\Delta \overrightarrow{v}}{\Delta t}$$

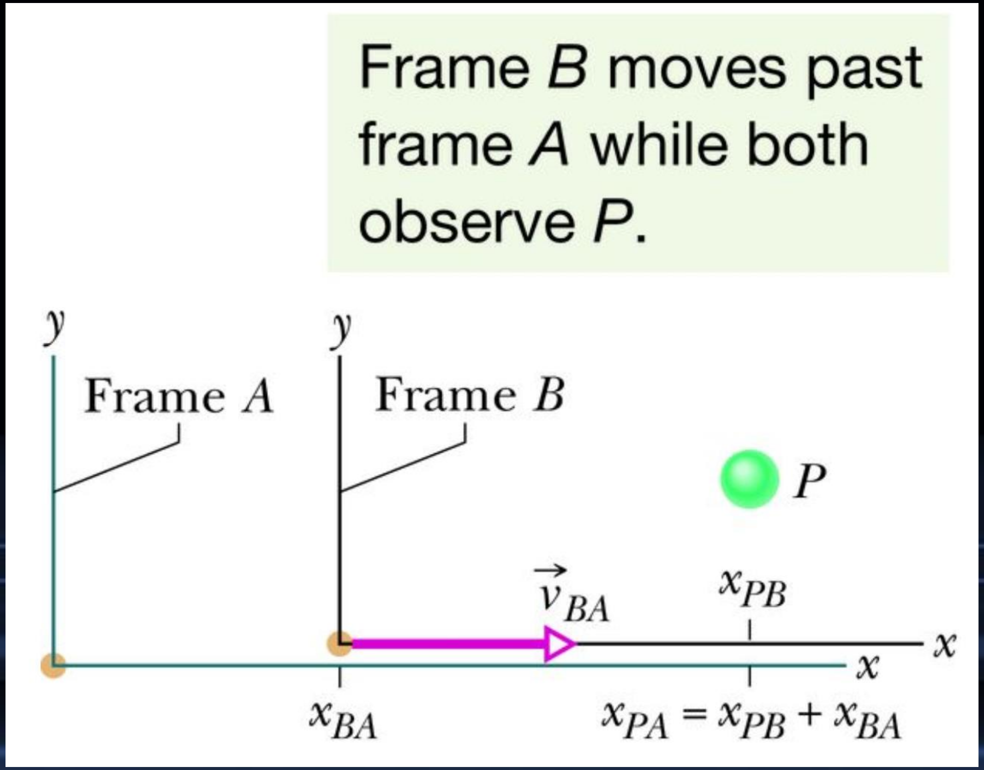
- Instantaneous acceleration

$$\overrightarrow{a} = \frac{d\overrightarrow{v}}{dt}$$

$$\begin{aligned}\overrightarrow{a} &= \frac{d}{dt}\left(v_x \hat{\mathrm{i}} + v_y \hat{\mathrm{j}} + v_z \widehat{\mathrm{k}}\right) \\ &= \frac{dv_x}{dt}\hat{\mathrm{i}} + \frac{dv_y}{dt}\hat{\mathrm{j}} + \frac{dv_z}{dt}\widehat{\mathrm{k}}.\end{aligned}$$

Relative motion in one dimension

- If the observer have a relative constant velocity to the observed object, then:



Relative motion in one dimension (2)

- We can find that:

$$x_{PA} = x_{PB} + x_{BA}$$

- Thus, the conversion of velocity between frames:

$$\frac{d}{dt}(x_{PA}) = \frac{d}{dt}(x_{PB}) + \frac{d}{dt}(x_{BA})$$

$$v_{PA} = v_{PB} + v_{BA}$$

Relative motion in one dimension (3)

- For the acceleration:

$$\frac{d}{dt}(v_{PA}) = \frac{d}{dt}(v_{PB}) + \frac{d}{dt}(v_{BA})$$

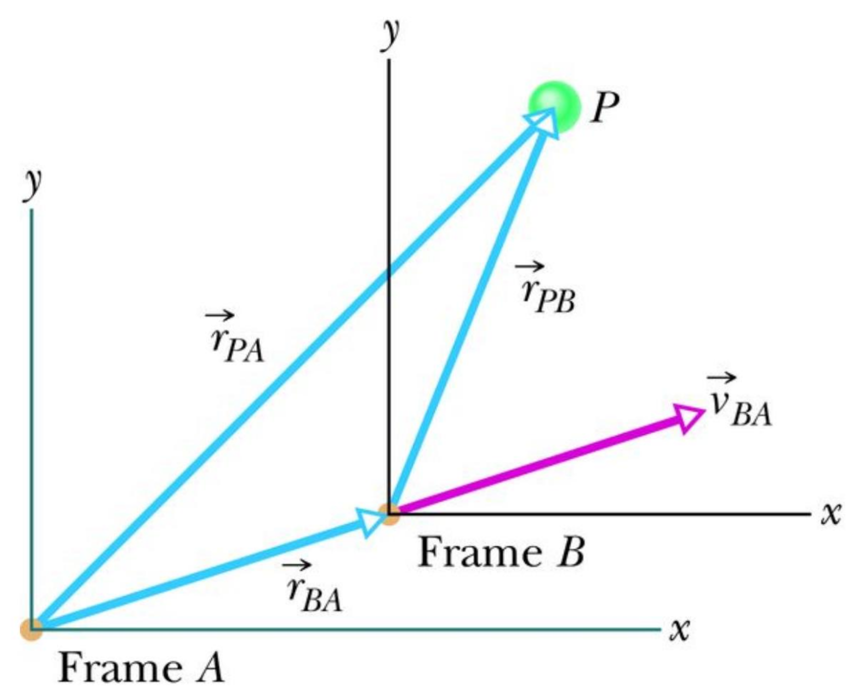
- Frame B moves with constant velocity, we have:

$$a_{PA} = a_{PB}$$

- The velocity changes on different frames but acceleration is a constant if the frame moves with constant velocity.

Relative motion in two or three dimension

- The relative motion can be generalized in two or even three dimension:



$$\vec{r}_{PA} = \vec{r}_{PB} + \vec{r}_{BA}$$

$$\vec{v}_{PA} = \vec{v}_{PB} + \vec{v}_{BA}$$

$$\vec{a}_{PA} = \vec{a}_{PB}$$

3.Relative Motion

Ship A is located 4.0 km north and 2.5 km east of ship B. Ship A has a velocity of 20 km/h toward the south, and ship B has a velocity of 30 km/h in a direction 37° north of east. Assuming the unit-vector toward the east $\hat{i}$ and the unit-vectortoward the north is $\hat{j}$. (a) Write an expression (in terms of $\hat{i}$ and $\hat{j}$) for the position of A relative to B as a function of t, where t = 0 when the ships are in the positions described above. (0.5point) (b) What is that least separation of the these two ship? (0.5point)

Solution (a)The velocity A respect to rest frame:$\overrightarrow{V_A} = (0km/h)\widehat{i} - (20km/h)\widehat{j}$, The velocity B respect to rest frame:$\overrightarrow{V_B} = 30cos37\widehat{i} + 30sin37\widehat{j} = (24km/h)\widehat{i} + (18km/h)\widehat{j}$.

Assuming the ship B's position at t=0 is the origin of the cooridnate.

The position of ship A $\overrightarrow{r_A} = \overrightarrow{r_A}(t=0) + \overrightarrow{V_A}t = [(2.5km)\widehat{i} + [4.0km - (20km/h)t]\widehat{j}]$.

The position of ship B $\overrightarrow{r_B} = \overrightarrow{r_B}(t=0) + \overrightarrow{V_B}t = [(24km/h)t\widehat{i} + (18km/h)t\widehat{j}]$

The relative position of A relavtive to B is

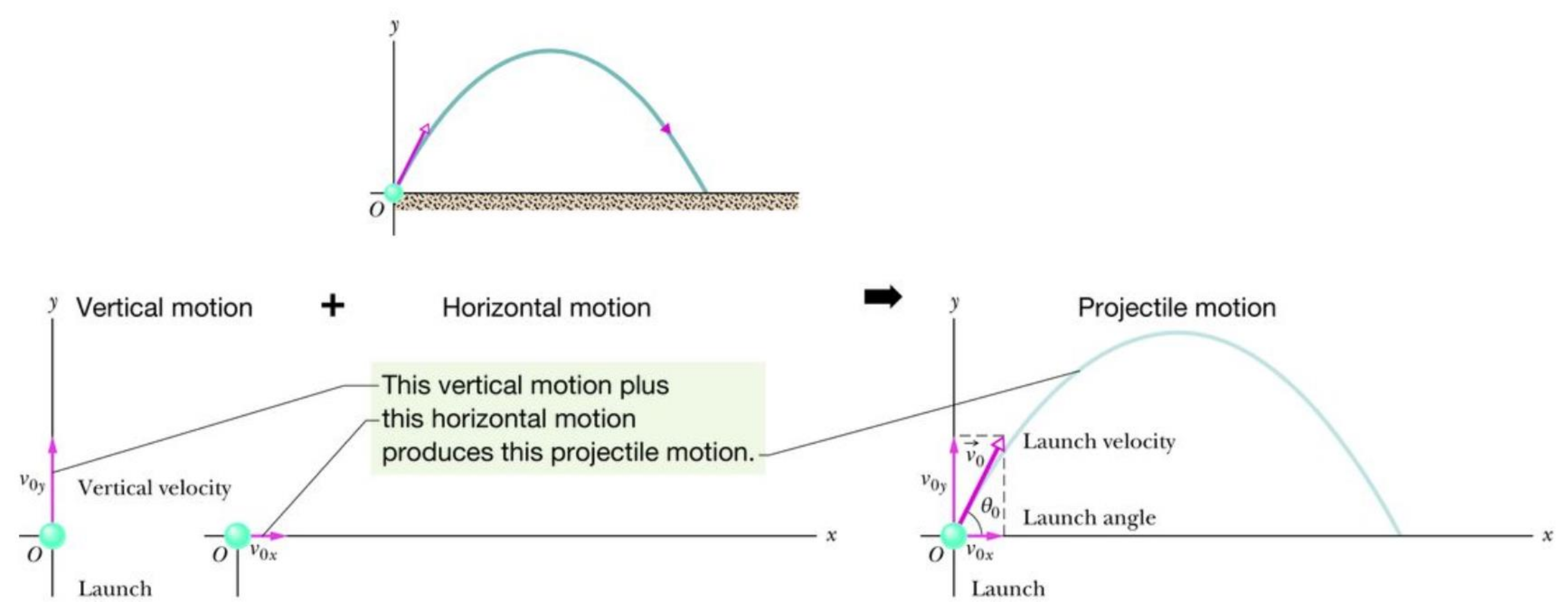
$\overrightarrow{r_{AB}} = \overrightarrow{r_A} - \overrightarrow{r_B} = [(2.5km)\widehat{i} + [4.0km - (20km/h)t]\widehat{j}] - [(24km/h)t\widehat{i} + (18km/h)t\widehat{j}] = [(2.5km) - (24km/h)t]\widehat{i} + [(4.0km) - (38km/h)t]\widehat{j}$

(b)The separation between the ships is $|\overrightarrow{r_{AB}}| = \{[(2.5km) - (24km/h)t]^2 + [(4.0km) - (38km/h)t]^2\}^{\frac{1}{2}} = [(6.25 - 120t + 576t^2) + (16 - 304t + 1444t^2)]^{\frac{1}{2}} = [22.25 - 424t + 2020t^2]^{\frac{1}{2}}$

The least seperation happen when the derivative of seperation respect to t is 0. Therefore, it is $t = 424/(2\cdot 2020) = 0.105h$.

Therefore, the least seperation is $|\overrightarrow{r_{AB}}|(t = 0.105h) = 0.022km$

Projectile motion



Projectile motion

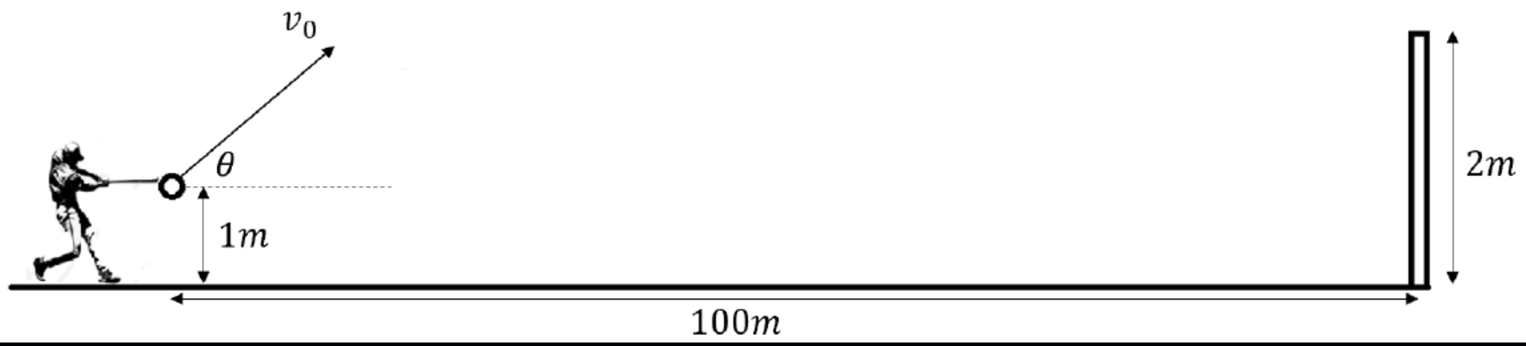
- Horizontal motion: $$x - x_0 = v_{0x}t = (v_0 \cos \theta_0)t$$

- Vertical motion: $$y - y_0 = v_{0y}t - \frac{1}{2}gt^2 = (v_0 \sin \theta_0)t - \frac{1}{2}gt^2$$

- Equation of the path: $$y = (\tan \theta_0)x - \frac{gx^2}{2(v_0 \cos \theta_0)^2}$$

2. Projectile Motion - Home Run of Baseball

As shown in the figure, a baseball player hit the ball at $1m$ height and the launching angle θ =30°. The home run fence is $100m$ away from the home base, and the fence is $2m$ high. Assuming the air drag force can be neglected. What is the minimum initial velocity v_0 of the ball to be a homerun (that is, the baseball can pass right above the home run fence)? (1point)

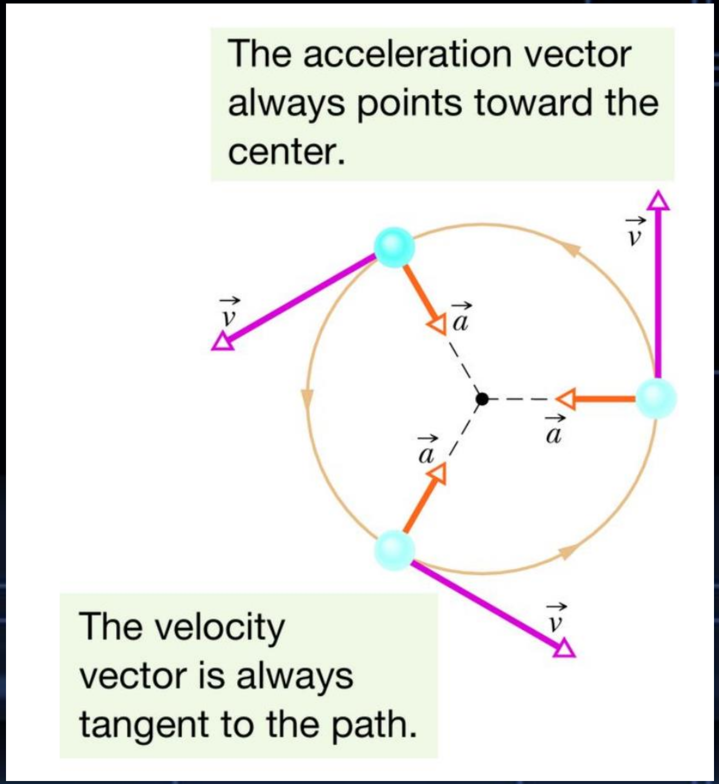


Solution Let's set a coordinate system with origin at the postion that the bat just hit the baseball. The baseball performs a projectile motion. The condition to have homerum is $y \geq 2 - 1 = 1m$ when the x-position is at $x = 100m$. The time for the ball to reach $x = 100m$ is $t = \frac{x}{v_0 cos\theta}$. The y coordinate is $y = v_0 sin\theta t - \frac{1}{2}gt^2 = xtan\theta - \frac{1}{2}g(\frac{x}{v_0 cos\theta})^2 \geq 1m$. Thus we can get $v_0 \geq 33.9m/s$ with $g = 9.8m/s^2$.

Uniform Circular Motion

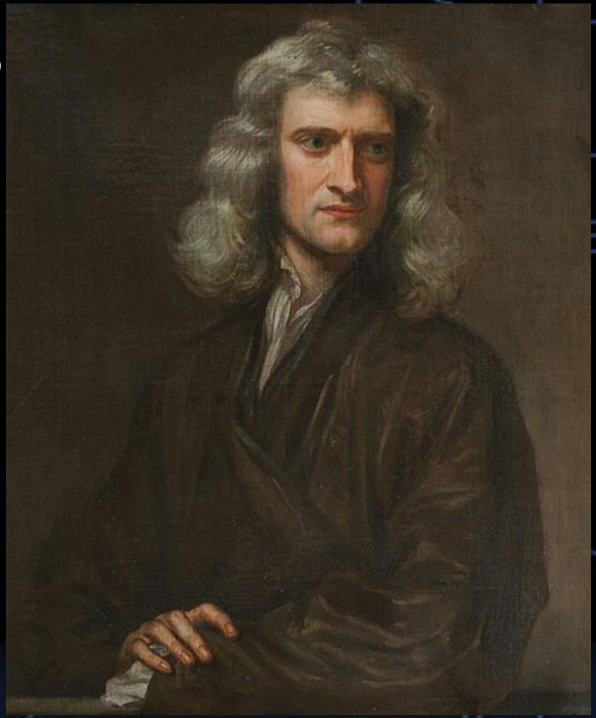
- The condition of having uniform circular motion is:

$$a = \sqrt{a_x^2 + a_y^2} = \frac{v^2}{r}\sqrt{(\cos\ \theta)^2 + (\sin\ \theta)^2} = \frac{v^2}{r}\sqrt{1} = \frac{v^2}{r}$$



Newton's Law of Motion

- The relationship between force and motion is first understood and formulated with mathematical descriptions: Newtonian mechanics.
- There are three primary laws of motion.



Newton’s first law of motion

- If no net force ($\overrightarrow{F_{net}} = 0$) acts on a body , the body’s velocity cannot change; that is, the body cannot accelerate.

Inertial reference frame

- Newton’s first law is not true in all reference frames, but we can always find reference frames in which it (as well as the rest of Newtonian mechanics) is true. Such special frames are referred to as inertial reference frames, or simply inertial frames.
- All inertial frames are move to each other with constant relative velocities.

Newton's second law of motion

- The net force on a body is equal to the product of the body's mass and its acceleration.

$$\overrightarrow{F_{net}} = m\vec{a}$$

- The acceleration component along a given axis is caused only by the sum of the force components along that same axis, and not by force components along any other axis.

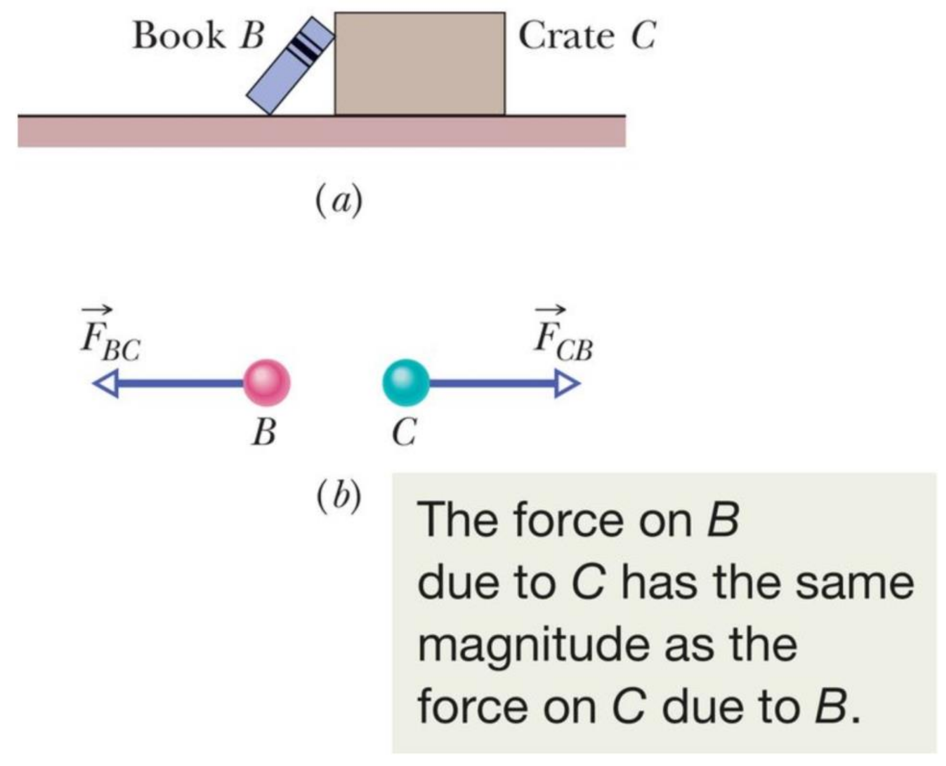
$$F_{net,x} = ma_x, F_{net,y} = ma_y, F_{net,z} = ma_z$$

Equation of motion

- Newton's second law provide link between force and acceleration, which is the second derivative of position respect to time. Therefore, one can obtain an equation to describe the behavior of a physical system in terms of its motion as a function of time, which is called equation of motion.

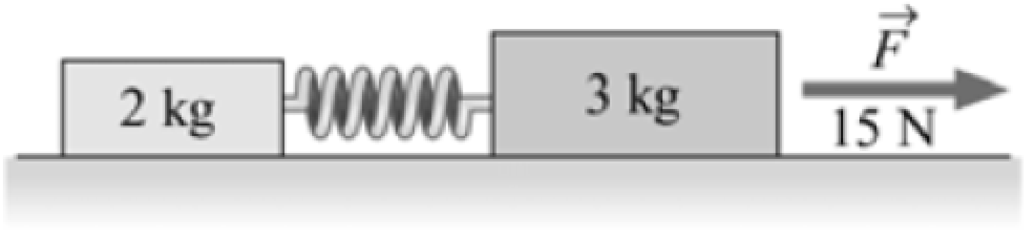
Newton’s third law

- When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.



5.Spring Force Between Blocks

A 2.0kg mass and a 3.0kg mass are on a horizontal frictionless surface connected by a massless spring with spring constant $k = 180N/m$. A $15N$ force is applied to the larger mass, as shown in the following figure. How much does the spring stretch from its equilibrium length? (1point)

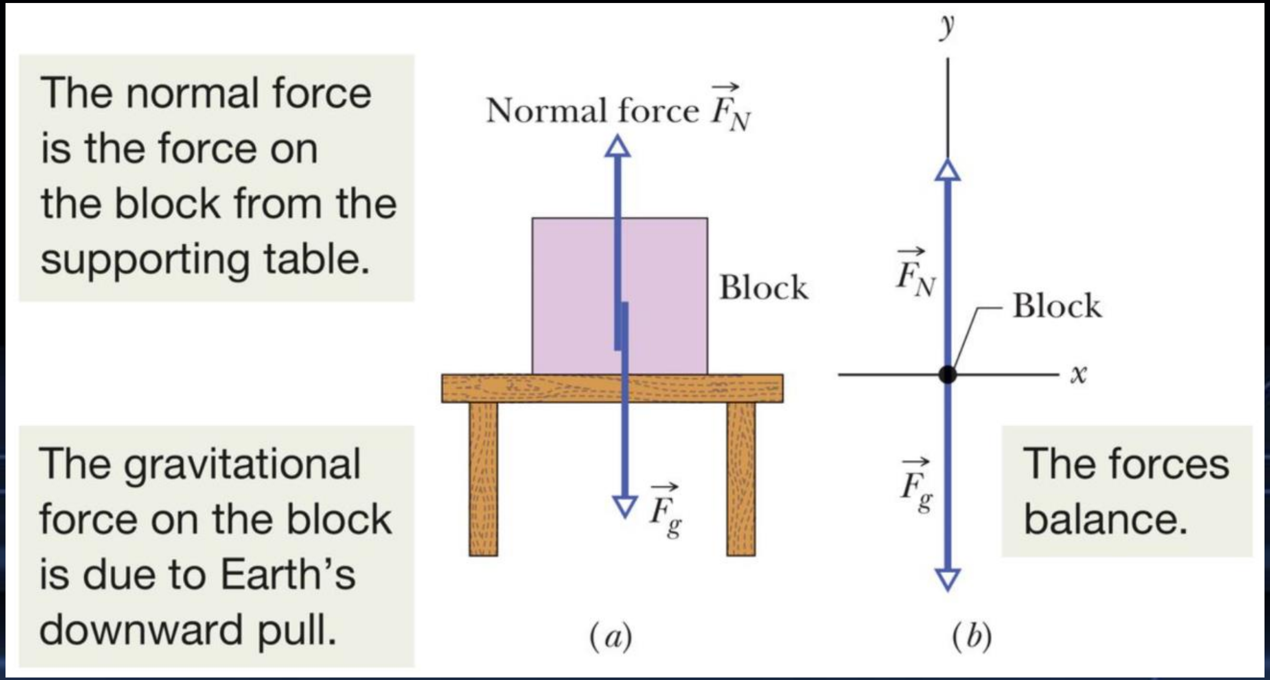


Solution We first treat the two block as one system. Therefore, the acceleration of this system due to force F is $a_{tot} = \frac{F}{m_1+m_2} = 3m/s^2$

Since the two blocks will move together and thus $a_{tot} = a_1 = a_2$. Now if we focus on the second block with 2.0kg, the net force on this block is to the right due to spring force. This results in an acceleration $a_2 = 3m/s^2$. Thus, the spring force exerting on the second block with 2.0kg is $m_2 a_2 = 6N$. Following with Hooke's law, we kno the spring stretch from its equilibrium length with $\Delta x = m_2 a_2/k = 0.033m$.

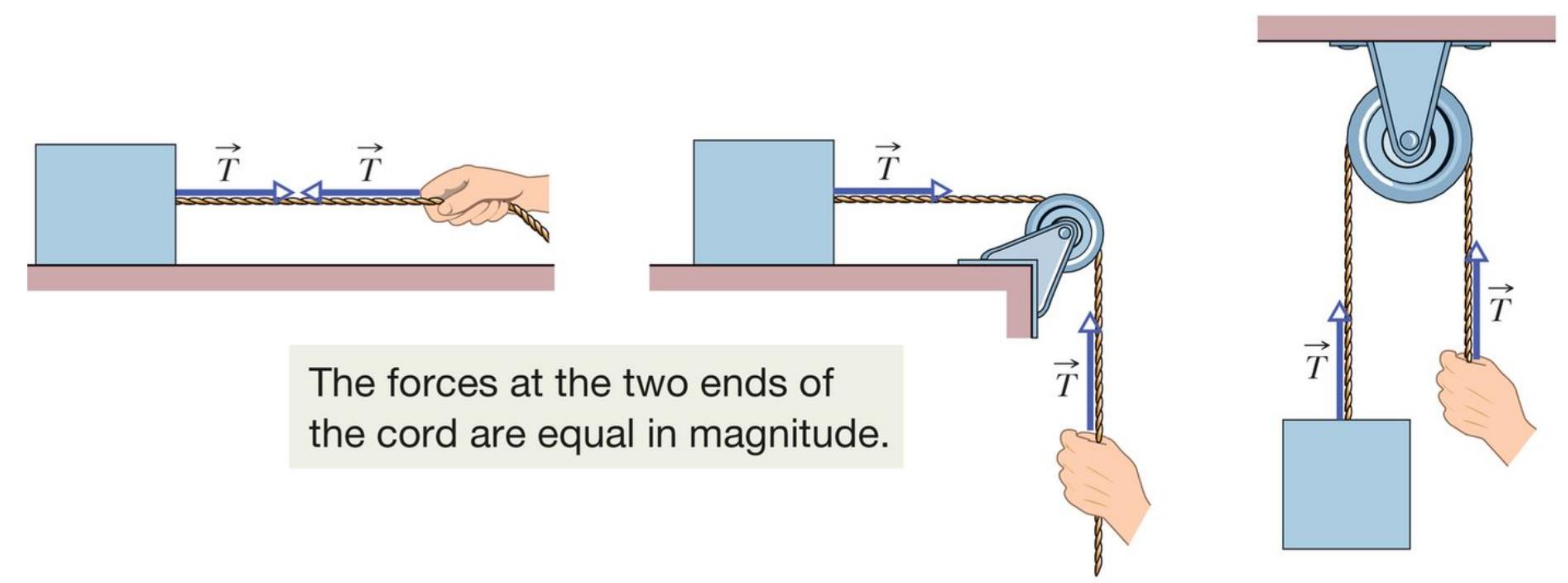
Normal force

- When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force $\overrightarrow{F_N}$ that is perpendicular to the surface.



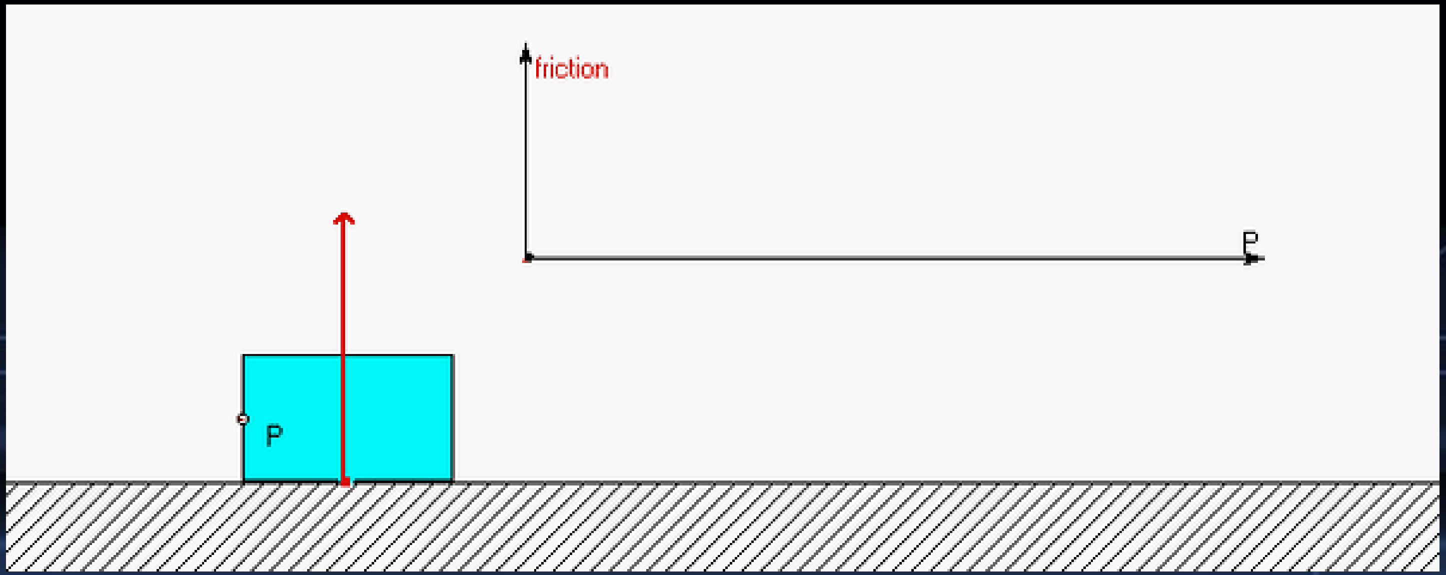
Tension

- When a cord (or a rope, cable, or other such object) is attached to a body and pulled taut, the cord pulls on the body with a tension force $\vec{T}$ directed away from the body and along the cord.



Two types of frictions: static and kinetic

- Static friction: If the body does not move, then the static frictional force $\overrightarrow{f_s}$ and the component of $\vec{F}$ that is parallel to the surface balance each other. They are equal in magnitude, and $\overrightarrow{f_s}$ is directed opposite that component of $\vec{F}$.



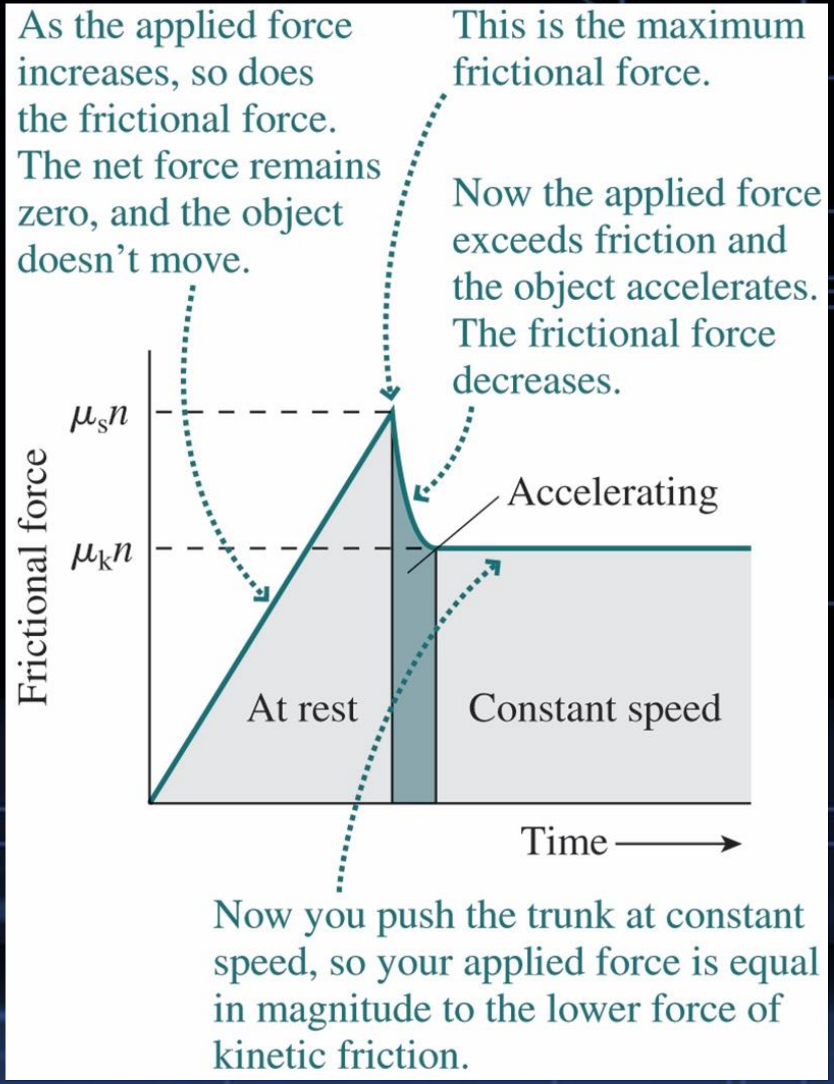
https://www.purdue.edu/freeform/statics/friction-on-sliding-block/

Two types of frictions: static and kinetic

- The magnitude of $\vec{f_s}$ has a maximum value $f_{s,max}$ that is given by

$$f_{s,max} = \mu_s \cdot n$$

where μ_s is the coefficient of static friction and n is the magnitude of the normal force on the body from the surface.

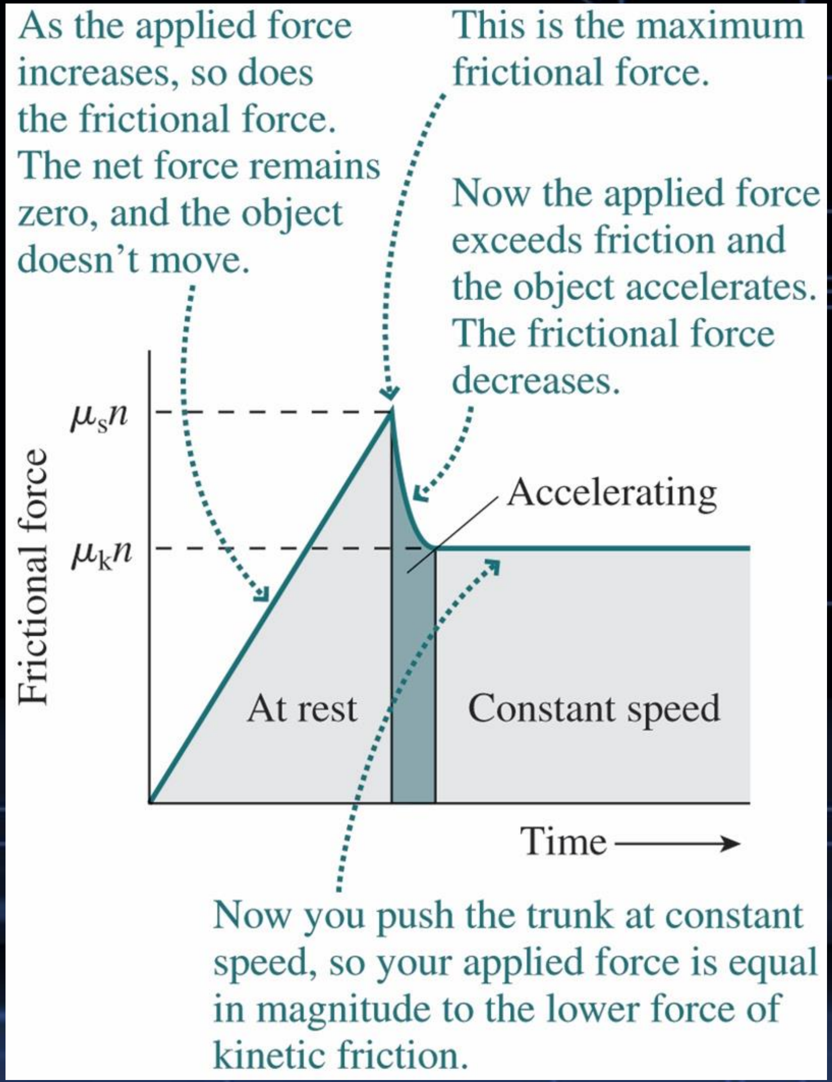


Two types of frictions: static and kinetic

- Kinetic friction: If the body begins to slide along the surface, the magnitude of the frictional force rapidly decreases to a value f_k given by

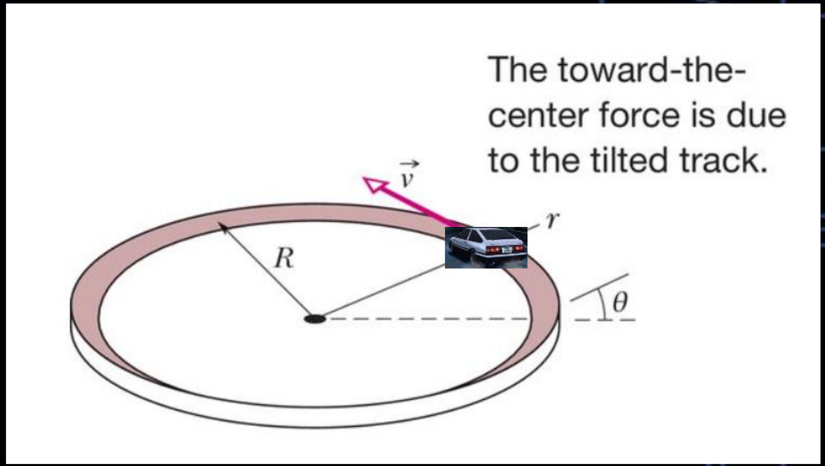
$$f_k = \mu_k \cdot n$$

where μ_k is the coefficient of kinetic friction.



Example 2: car on a frictionless tilted curve

- Assuming a car with mass m=1000kg turn on a frictionless tilted curve. The tilted angle is $\theta = 10^{\circ}$curve can be approximate as a part of a circle with radius R=50m. What is the maximum speed of this car can make the turn?



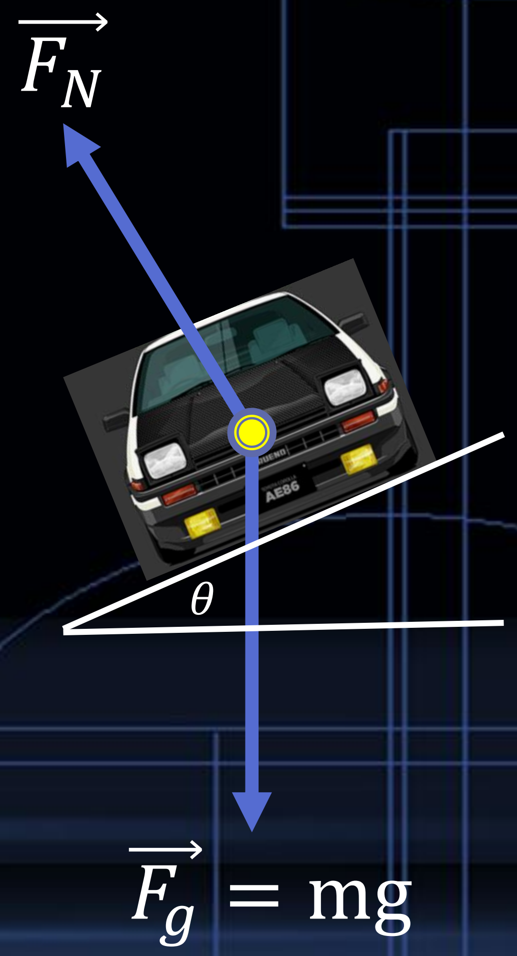
Example 2: car on a frictionless tilted curve

- The centripetal acceleration is provided by the horizontal components of normal force. The vertical component of normal force cancels out the gravitational force:

$$F_N \cos\theta = mg$$

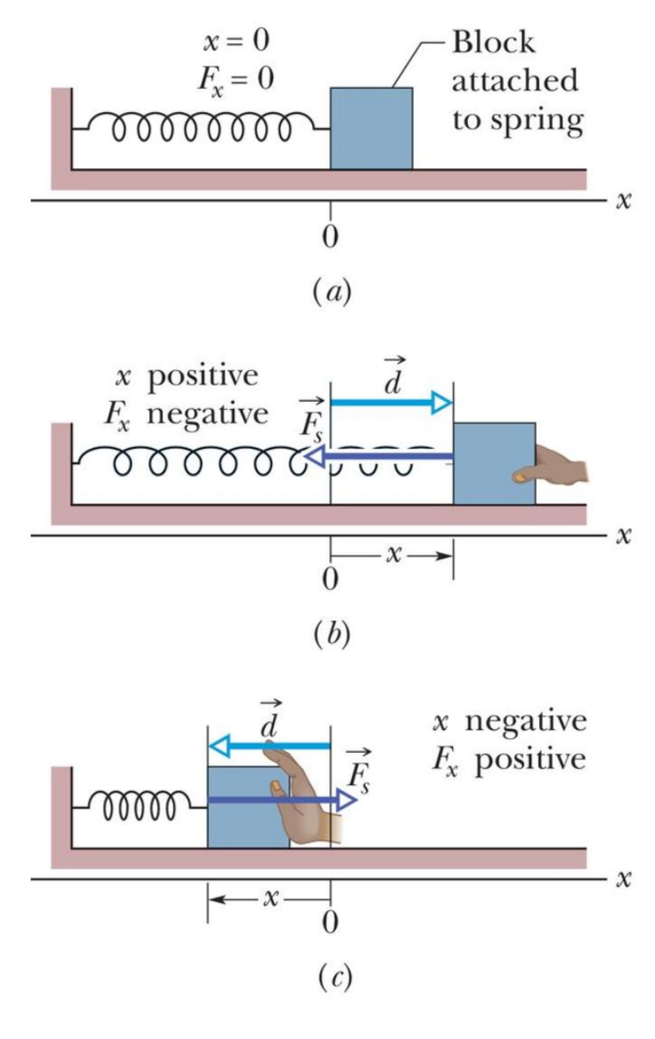
$$F_N \sin\theta = \frac{m{v_{max}}^2}{R}$$

- Thus $v_{max} = \sqrt{gR\tan\theta} = 33.5 km/hr$



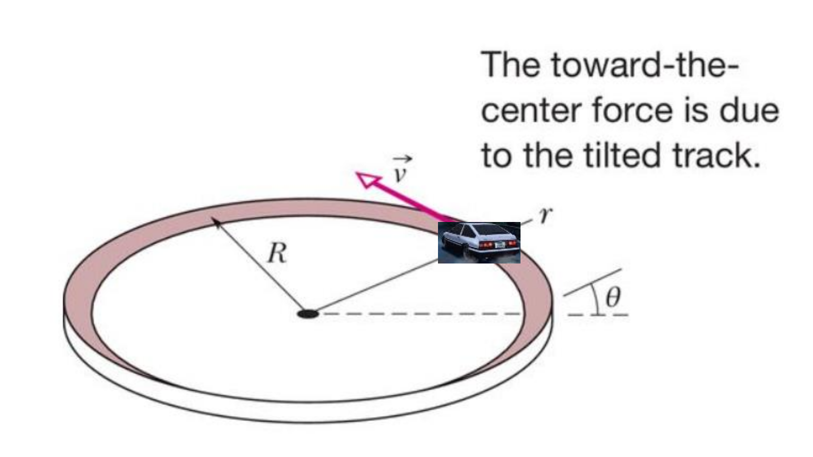
Spring force

- **Spring force:** To a good approximation for many springs, the force $\vec{F}_s$ from a spring is proportional to the displacement $\vec{d}$ of the free end from its position when the spring is in the relaxed state. The spring force is given by $\vec{F}_s = -k\vec{d}$, which is known as Hooke's law.



Example : car on a tilted curve with friction

- Assuming a car with mass m=1000kg turn on a tilted curve. The tilted angle is $\theta = 10^{\circ}$ curve can be approximate as a part of a circle with radius R=50m. The static frictional coefficient $\mu_s = 0.75$. What is the maximum speed of this car can make the turn?



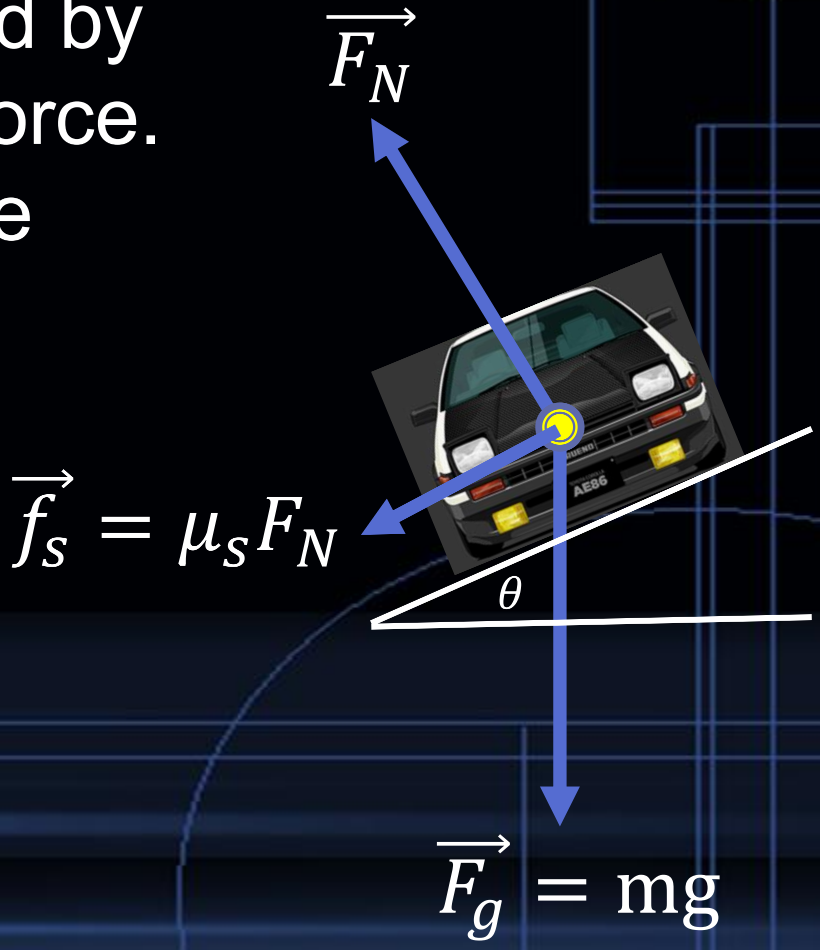
Example : car on a frictionless tilted curve

- The centripetal acceleration is provided by the horizontal components of normal force. The vertical component of normal force cancels out the gravitational force:

$$F_N \cos\theta = mg + \mu_s F_N \sin\theta$$

$$F_N \sin\theta + \mu_s F_N \cos\theta = \frac{m v_{max}{}^2}{R}$$

- Thus $v_{max} = 82.3 km/hr$



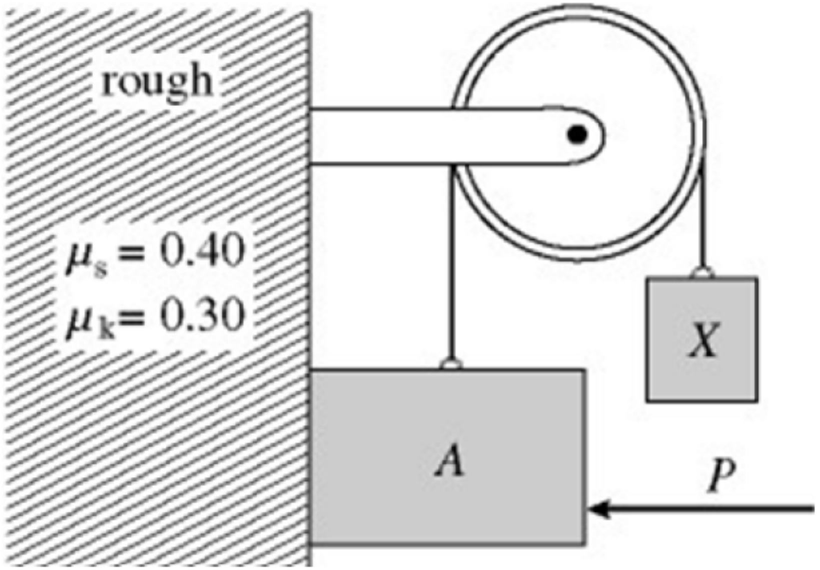
4.Weight Difference Due to Uniform Circular Motion ot the Earth

When you stand on a scale, the scale reading shows the force with which it's pusing. A person stand on a scale at Earth's north pole and the scale reads $50.00kg$. What is the reading if the same person stand on the same scale at Earth's equator? (1point) Assuming the radius of the earth is $6400km$, the tangant velocity at Earth's equator is $465m/s$, and $g = 9.8m/s^2$

Solution At the Earth's equator, the net force acting on a person needs to provide centripal acceleration for spinning with the earth. Therefore, we have $mg - F_N = m\frac{v^2}{R_E}$, where F_N is the normal force provided by the sacle. The reading of the scale thus will be $\frac{F_N}{g} = \frac{m(g-\frac{v^2}{R_E})}{g} = 49.83kg$.

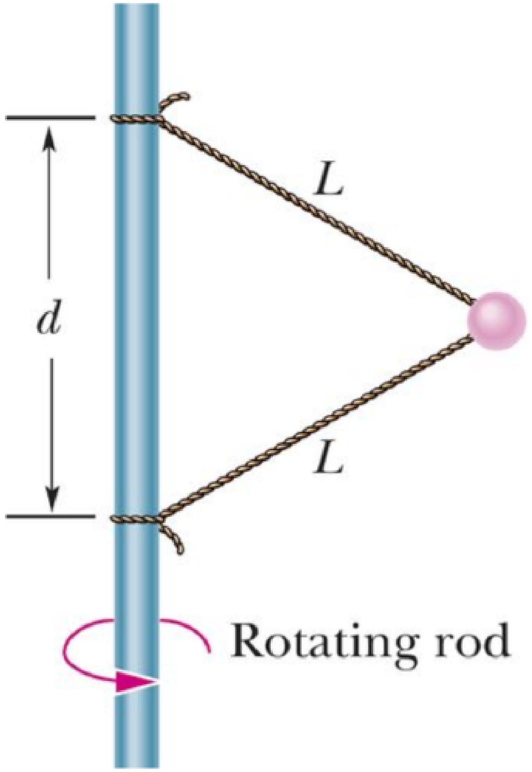
1.Newton's law on Multiple Objects

Block A of mass 8.00 kg and block X are attached to a rope that passes over a pulley. A 50.00N force P is applied horizontally to block A, keeping it in contact with a rough vertical face. The coefficients of static and kinetic friction between the wall and block A are $\mu_s = 0.40$ and $\mu_k = 0.30$. The pulley is light and frictionless. In the figure, the mass of block X is adjusted until block A descends at constant velocity of 5.00 cm/s when it is set into motion. What is the mass of block X? (1point)



2.Force for an Uniform Circular Motion

In the following figure, a 1.34 kg ball is connected by means of two massless strings, each of length L = 1.70 m, to a vertical, rotating rod. The strings are tied to the rod with separation d = 1.70 m and are taut. The tension in the upper string is 35.00 N. What are the (a) tension in the lower string (0.5point) (b) speed of the ball?(0.5point)



Concept of conservation law

- In the physical world, there are also some “numbers” or “physical quantities” of a system that don’t change when the system evolving with time. These are conservation laws.
- Studying these conservation laws is one of the fundamental key questions of physics.
- Examples of conversation law: conservation of energy, conservation of linear momentum, conservation fo angular momentum…

Kinetic energy

- Kinetic energy K is energy associated with the state of motion of an object. For an object of mass m whose speed v is well below the speed of light:

$$K = \frac{1}{2}mv^2$$

- The SI unit of kinetic energy (and all types of energy) is the joule (J):

$$1J = 1kg \cdot 1m^2/s^2$$

Work

- Work W is energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.
- The work W done by a constant force $\vec{F}$ when its point of application undergoes a displacement $\vec{s}$ is defined to be $W = \vec{F} \cdot \vec{s}$.
- Work is a scalar and has the same unit of kinetic energy

3. Work Done by a Variational Force

A force on a particle depends on position such that $F(x) = [3.00(N/m^2)x^2 + 6.00(N/m)x)]i + 5.00(N)\hat{j}$ for a particle constrained to move along the x-axis. There is no motion in y-axis. What work is done by this force on a particle that moves from x = 0.00 m to x = 2.00 m? (1point)

Relationship between work and kinetic energy

- Since we introduce kinetic energy and work, what is the relationship between them?

Thus we have:

$$W = \int_1^2 \frac{1}{2} m d(\vec{v} \cdot \vec{v}) = \int_1^2 d(\frac{1}{2} m v^2) = K_2 - K_1$$

Work-kinetic energy theorem

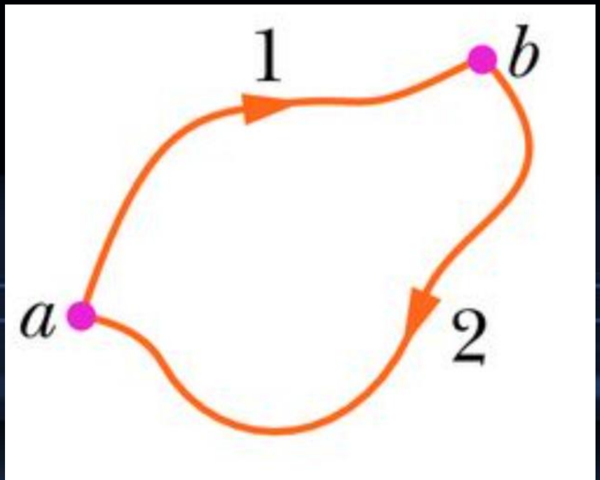
- We integral respect to displacement on equation of motion, we got relationship between work and kinetic energy.
- Work-kinetic energy theorem: The net work done on an object equal to the change in kinetic energy.

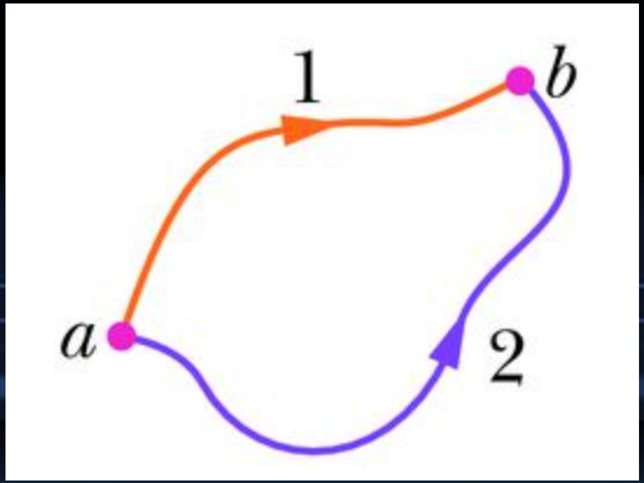
$$\mathrm{W} = K_2 - K_1$$

Formal definition of conservative force in 3D

- The net work done by a conservative force $\overrightarrow{F_c}$ on a particle moving around any closed path is zero.

$$\oint \overrightarrow{F_c} \cdot d\vec{r} = 0$$





The work done by $\overrightarrow{F_c}$ does not depend on path, but only the position of a and b.

Conservation of Energy

- Conservation of mechanical energy: Considering there is only a conservative force $\vec{F_c}$ doing work W_c on an object, then we have:

$$W_c = -\Delta U = -(U_2 - U_1) = K_2 - K_1$$

$$K_1 + U_1 = K_2 + U_2 \equiv E_{mec}$$

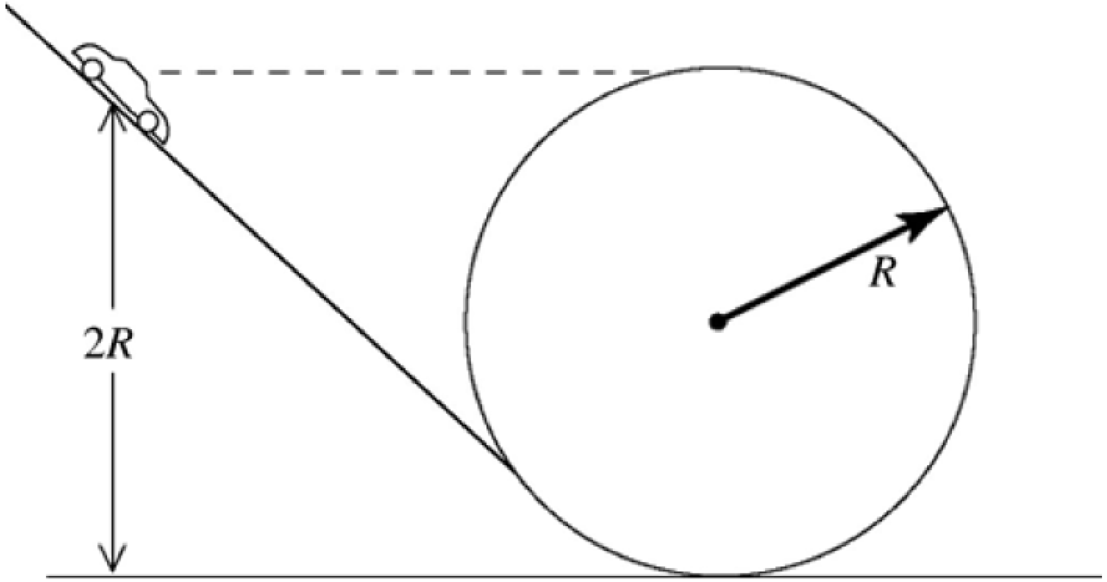
- Conservation of energy:

Work done by non-conservative force = change of mechanical energy

- $W_{nc} = \Delta K + \Delta U$

4.Conservation of energy in a Looping-Loop

In the figure, a toy race car of mass m=0.1kg is released from rest on the loop-the-loop track. If it is released at a height 2R=2.00m above the floor, how high is it above the floor when it leaves the track, neglecting friction? (1point)



Universal Gravitation

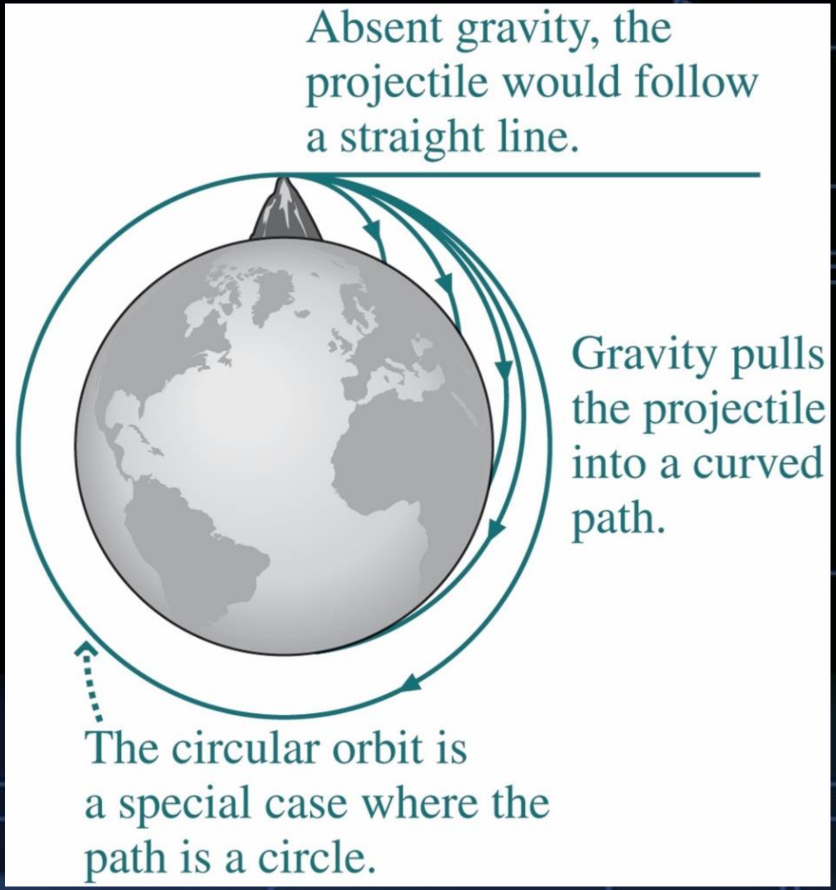
- Newton's **law of universal gravitation** states that any two point particles attract each other with a force that is proportional to the product of their masses and inversely proportional to the square of their separation:

$$F = \frac{Gm_1m_2}{r^2}$$

- $G = 6.67 \times 10^{-11} N \cdot m^2/kg^2$ is the **constant of universal gravitation**.

Orbital Motion around the Earth

- Orbital motion occurs when gravity is the dominant force.
- Newton explained orbits using universal gravitation and his laws of motion:
  - The force of gravity causes a projectile to deviate from its straight-line path.
  - At a critical speed, the curvature of the projectile's path follows the Earth's curvature and it enters a circular orbit.



Circular Orbits

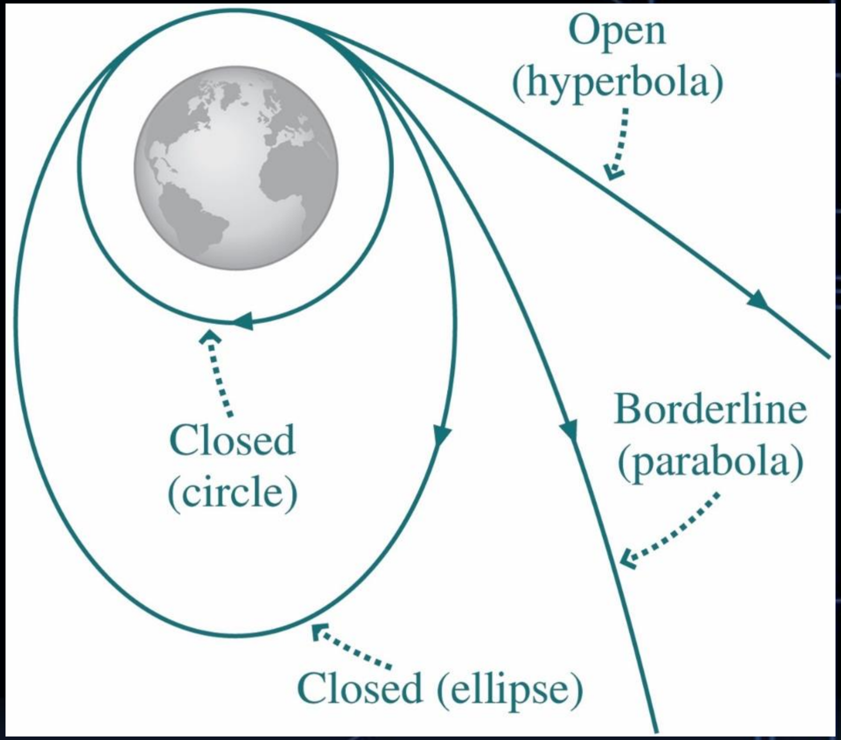
- In a circular orbit, gravity provides the centripetal force needed to keep an object of mass *m* in its circular path about a much more massive object of mass *M*. Therefore:

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

- The orbital speed: $v = \sqrt{\frac{GM}{r}}$
- Orbital period: $T^2 = (\frac{2\pi r}{v})^2 = \frac{4\pi^2 r^3}{GM}$
- This proves Kepler's third law: $T^2 \propto r^3$
- For satellites in low-Earth orbit, the period is about 90 minutes.

Elliptical Orbits and Open Orbits

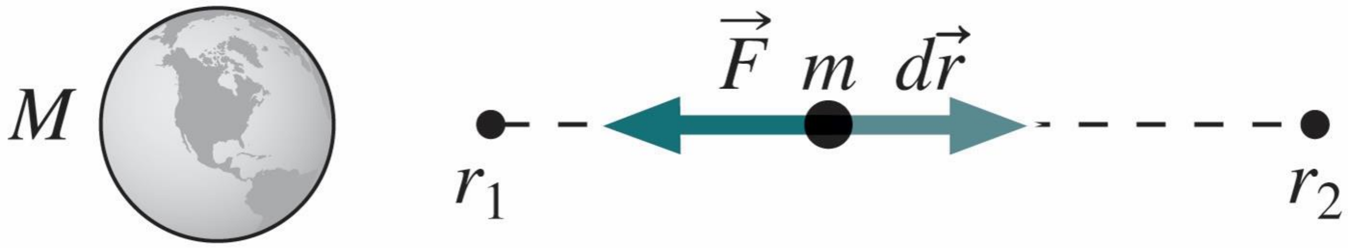
- A circular orbit is not the only possibility:
  - Closed (bound) orbits are elliptical.
  - In the special case of a circular orbit, the acceleration of the orbiting object has a constant magnitude and always points toward the center of the orbit.
  - Unbound orbits are hyperbolic or (borderline case) parabolic.



5.Circular Motion around the Moon

During the Apollo Moon landings, one astronaut remained with the command module in lunar orbit, about 130km above the moon survace. For half of each orbit, this astronaut was completely cut off from the rest of humanity as the spacecraft rounded the far side of the Moon. How long did this period last? (1point) Given the radius of the Moon is $R_M = 1.74 \times 10^6 m$ and the mass of the Moon is $M = 7.35 \times 10^{22} kg$. The gravitational constant $G = 6.67 \times 10^{-11} N \cdot m^2/kg^2$.

Gravitational Energy



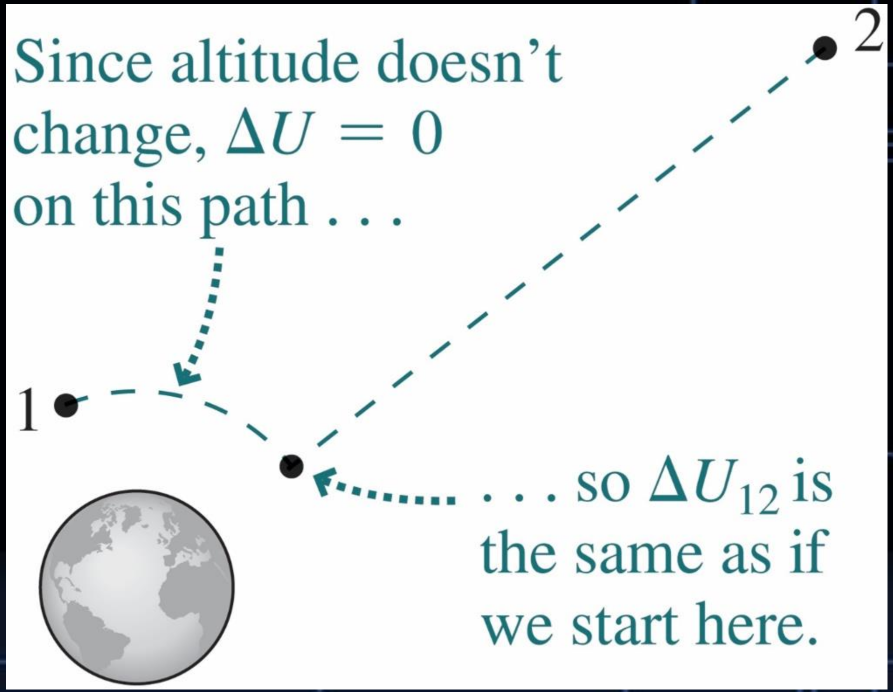
- The potential energy changes over large distances = The work done by gravitational force:

$$W = \int_{r_1}^{r_2} \frac{GMm}{r^2} dr = \left[-\frac{GMm}{r}\right]_{r_1}^{r_2} = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Gravitational Energy

- The result holds regardless of whether the two points are on the same radial line.
- It's convenient to take the zero of gravitational potential energy at infinity. Then, the gravitational potential energy becomes:

$$U(r) = -\frac{GMm}{r}$$



Escape Speed

- An object with total energy *E* less than zero is in a bound orbit and cannot escape from the gravitating center.
- With energy *E* greater than zero, the object is in an unbound orbit and can escape to infinitely far from the gravitating center.

$$0 = K + U = \tfrac{1}{2}mv^2 - \frac{GMm}{r}$$

- Solving for *v* gives the escape speed:

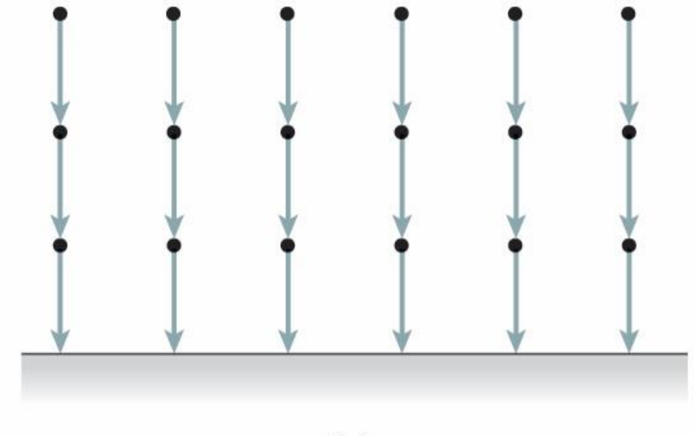
$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

- Escape speed from Earth's surface is about 11 km/s.

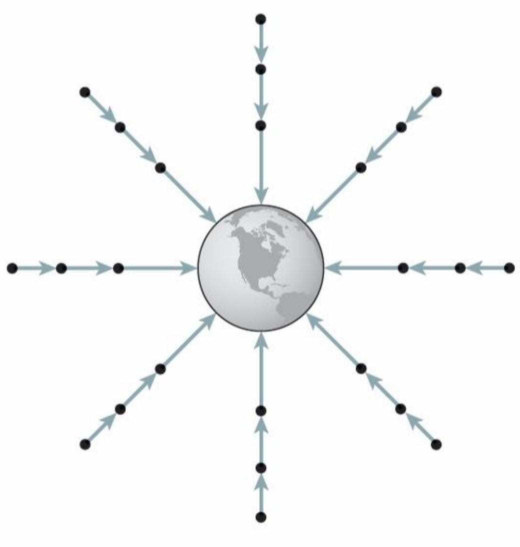
The Gravitational Field

- It's convenient to describe gravitation in terms of a **gravitational field** that results from the presence of mass and that exists at all points in space:
  - A massive object creates a gravitational field in its vicinity and other objects respond to the field **at their immediate locations**.
  - The gravitational field can be visualized with a set of vectors giving its strength (in N/k g; equivalently, m/s^2) and its direction.

$$\vec{g} = -\frac{GM}{r^2}\hat{r}$$



(a)



(b)