ch5. Using Newton's Law

- Static Equilibrium
- Multiple objects
- Frictional forces
- Circular motion.

Systematic approach or common strategies:

1) Understand the problem (making sense of the question) & make a sketch

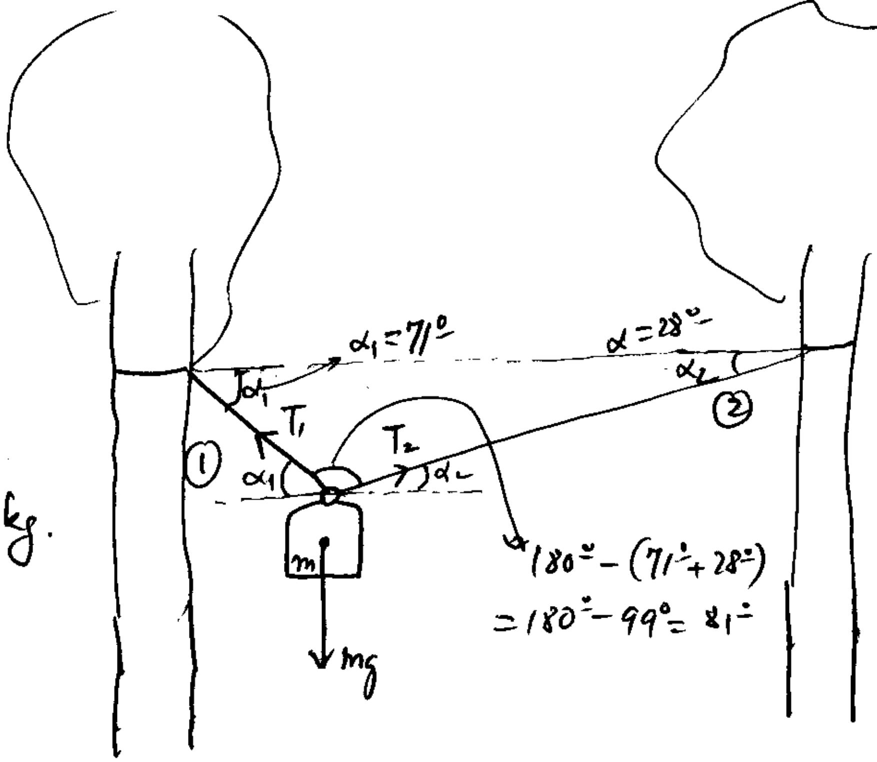
2) Select a convenient coordinate system
   - → most forces would point either along x- or y-axis of that coord system.
   - → motion of interest is along either x- or y-axis

3) Make a free-body diagram of forces acting on each object → so we can derive the net force acting on each object correctly. Draw x & y components for those forces that are not already lined up along these axes.

4) Write 2nd Newton's Law ($\vec{F}_{net} = m \cdot \vec{a}$) for each object, for each component as needed.

5) Solve for what we are asked for, obtaining numeric solutions with correct units in S.I. Check if these numbers make sense.

5.36



$m = 26\,kg.$

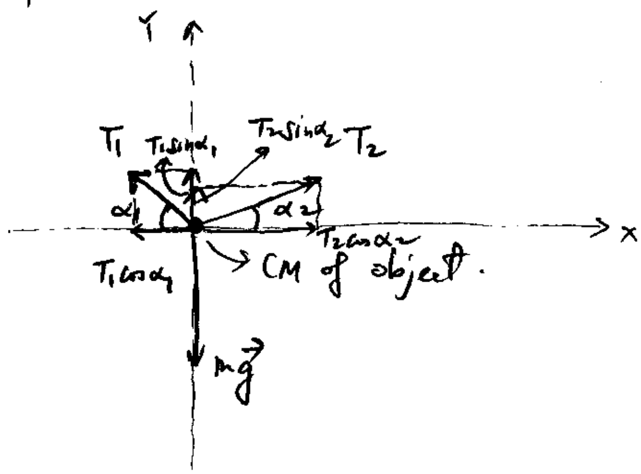
- Tensions in each rope are different: $T_1 \neq T_2$
- T_1? ; T_2?

Steps.

1) ✓ We'll use 2nd Newton's law to find T_1 & T_2 as they balance mg.

2) Object: backpack: 3 forces: $\vec{T_1}, \vec{T_2}, m\vec{g}$: none of these are perpendicular to each other. → Use standar x (horizontal), y (vertical)

3)



This free-body diagram helps us derive the net force on the pack in each direction.

$$F_{net_x} = T_{2x} - T_{1x} = T_2 \cos 28^\circ - T_1 \cos 71^\circ$$

$$F_{net_y} = T_{2y} + T_{1y} - mg = T_2 \sin 28^\circ + T_1 \sin 71^\circ - mg$$

4) 2nd Newton's Law: $\vec{F}_{net} = m \cdot \vec{a}$

$$F_{net_x} = m \cdot a_x = m \cdot 0 = 0 \rightarrow \boxed{T_2 \cos 28^\circ = T_1 \cos 71^\circ} \quad (a)$$

$$F_{net_y} = m \cdot a_y = m \cdot 0 = 0 \rightarrow \boxed{T_2 \sin 28^\circ + T_1 \sin 71^\circ = mg} \quad (b)$$

5) Algebraic solution of a system of 2 equations with two unknowns: T_1 & T_2

(a) $$T_1 = T_2 \frac{\cos 28^\circ}{\cos 71^\circ}$$

(b) $$T_2 \sin 28^\circ + T_2 \frac{\cos 28^\circ}{\cos 71^\circ} \sin 71^\circ = mg$$

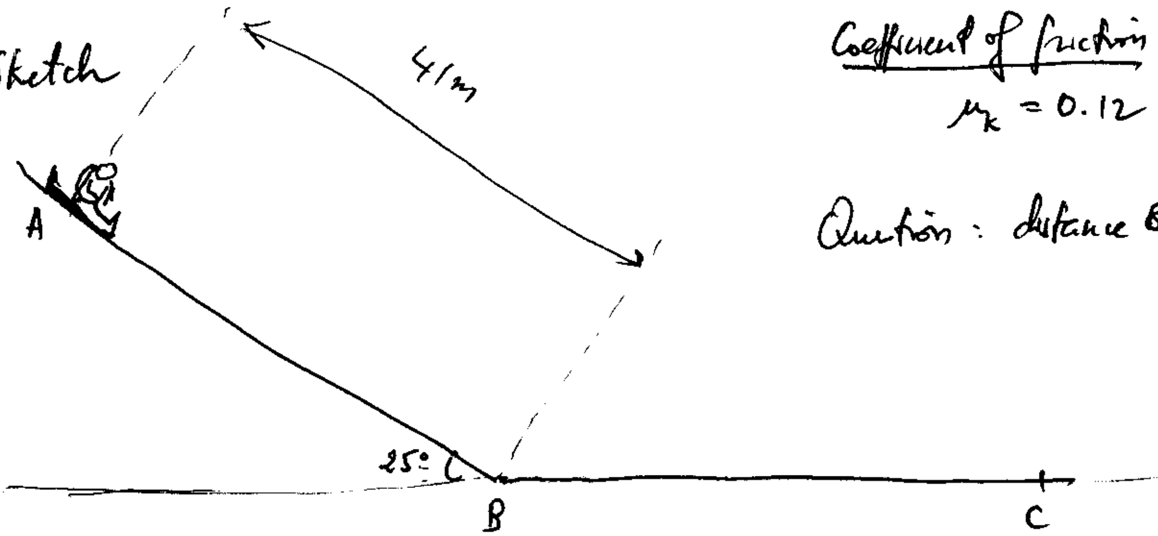
$$T_2 = \frac{26 \times 9.81}{\sin 28^\circ + \cos 28^\circ \cdot \tan 71^\circ} = 84\ N$$

$$(a) \rightarrow T_1 = 84 \frac{\cos 28^\circ}{\cos 71^\circ} = 228\ N$$

Do these numbers make sense? $T_1 > T_2 \rightarrow$ Yes!

5.49

1) Sketch

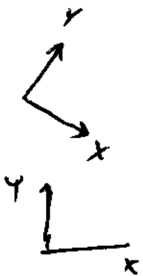


Coefficient of friction:
$\mu_k = 0.12$

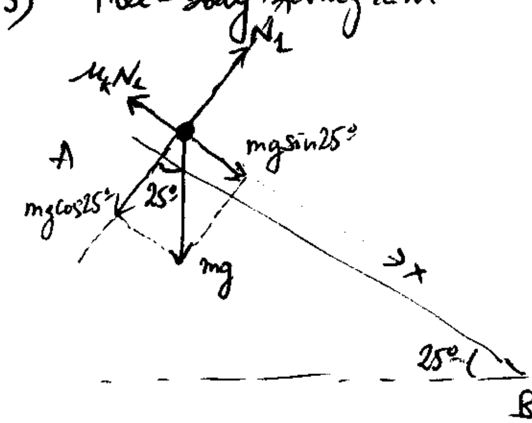
Question: distance BC?

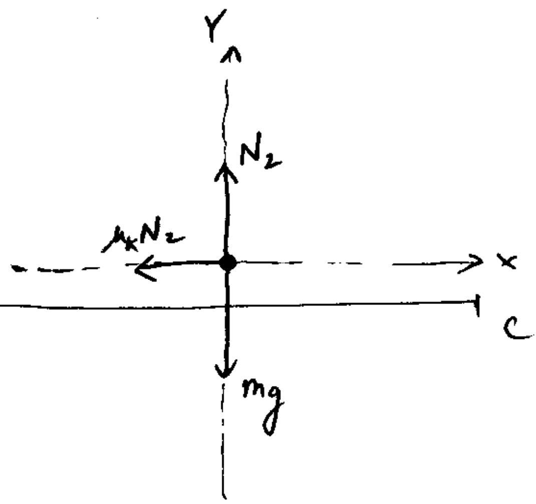
AB: constant acceleration
BC: constant deceleration due to frictional force → Will eventually stop here

2) Convenient coord. system
AB:
BC:



3) Free-body diagram





$$\vec{F}_{net} = (mg\sin 25° - \mu_k N_1)\,\hat{i} + (N_1 - mg\cos 25°)\,\hat{j}$$
$\boxed{AB}$

$$\vec{F}_{net} = -\mu_k N_2\,\hat{i} + (N_2 - mg)\,\hat{j}$$
$\boxed{BC}$

4) Write 2nd Newton's Law: $\vec{F}_{net} = m \cdot \vec{a}$

$\boxed{AB}$: $F_{net_x} = m \cdot \underbrace{a_x}_{\text{downhill acceleration}} \longrightarrow mg\sin 25° - \mu_k N_1 = m \cdot a_{1x}$

$F_{net_y} = m \cdot 0 \longrightarrow N_1 - mg\cos 25° = 0$

$\boxed{BC}$: $F_{net_x} = m \cdot \underbrace{a_{2x}}_{\text{deceleration b/w B\&C}} \longrightarrow -\mu_k N_2 = m \cdot a_{2x}$

$F_{net_y} = m \cdot 0 \longrightarrow N_2 - mg = 0$

5) $\boxed{\text{Solve for distance BC}}$: → we'll need to use a kinematic equation (Newton's Law provides acceleration):

$$\frac{v^2 - v_0^2}{x - x_0} = 2 \cdot a_x \rightarrow \frac{0 - \boxed{v_B^2}}{(x - x_0)_{BC}} = 2 \cdot \boxed{a_{2x}}$$

$(x - x_0)_{BC}$: unknown

v_B^2: can calculate using $\left\{ \frac{v_B^2 - 0}{41} = 2 \cdot a_{1x} \quad \text{or} \quad v = v_0 + a(t) \right.$

a_{2x}: can calculate from Newton's equations.

→ 3-step process
- a) Find initial velocity @ B
- b) Find a_{2x}
- c) Find $(x - x_0)_{BC}$

a) v_B: $\dfrac{v_B^2 - 0}{41} = 2 \cdot a_{1x}$

From Newton's equations in $\boxed{AB}$: $\cancel{m}g(\sin 25° - \mu_k \cos 25°) = \cancel{m} \cdot a_{1x}$

$$\rightarrow v_B = \sqrt{82 \cdot \underbrace{9.81(\sin 25° - 0.12 \cdot \cos 25°)}_{a_{1x} = 3.08\ \frac{m}{s^2}}} = 15.9\ m/s$$

b) Calculate a_{2x}: From Newton's equations in $\boxed{BC}$:

$$-\mu_K \cancel{m} g = \cancel{m} \cdot a_{2x} \rightarrow a_{2x} = -\mu_K g$$

$$= -0.12 \times 9.81$$

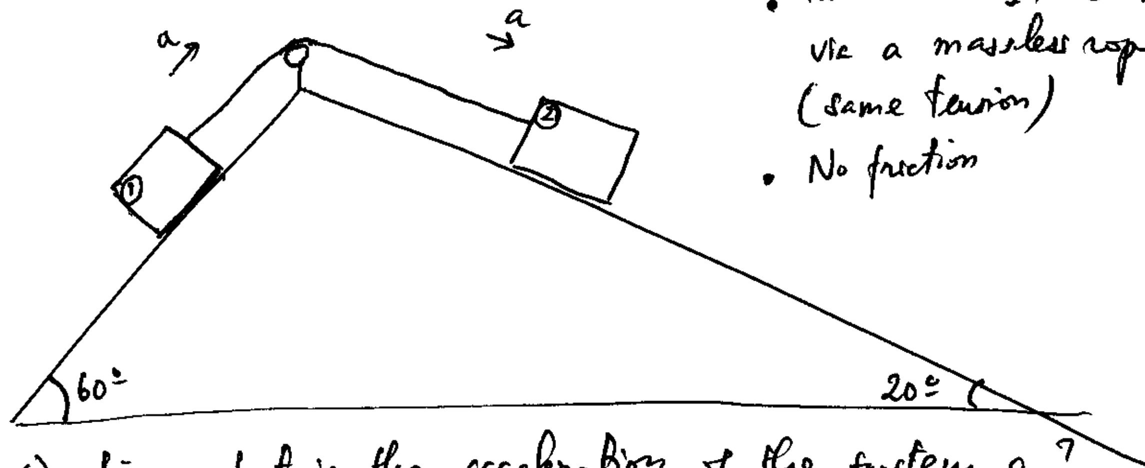
$$a_{2x} = -1.18\ m/s^2$$

c) $$\boxed{(x-x_0)_{BC}} = -\frac{v_B^2}{2 \cdot a_{2x}} = + \frac{15.9^2}{2 \cdot (+1.18)} = \boxed{107\ m}$$

Multiple Objects

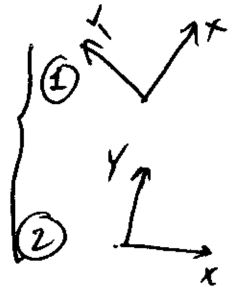
$a_1 = a_2 = a$

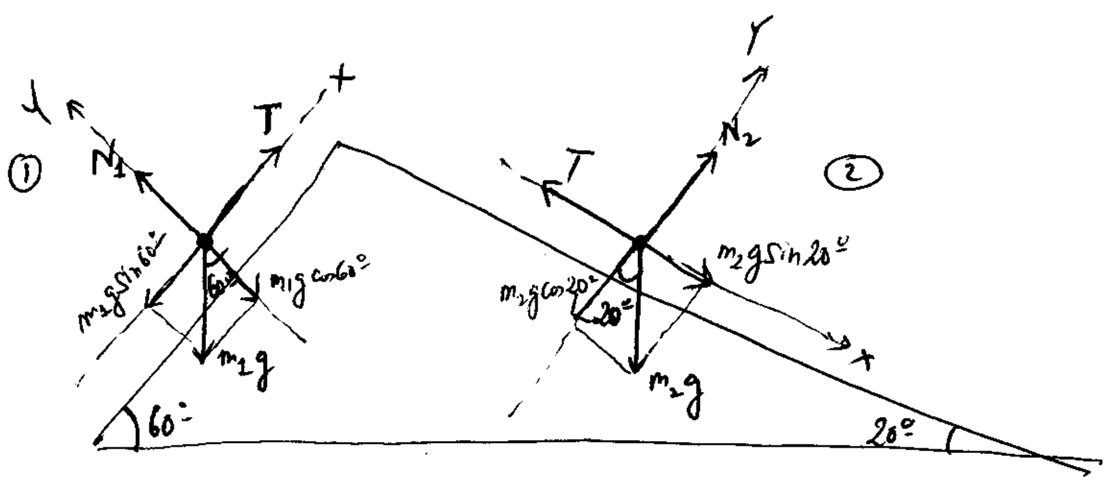
- Two boxes m_1, m_2 connected via a massless rope (same tension)
- No friction

1) 

Question: what is the acceleration of the system a?
If m_1 is sufficiently high the acceleration will result negative (opposite to what we assume here)

2) Convenient coord. system for each object:



3) 

$\vec{F}_{net_1} = (T - m_1 g \sin 60°)\,\hat{i} + (N_1 - m_1 g \cos 60°)\,\hat{j}$

$\vec{F}_{net_2} = (m_2 g \sin 20° - T)\,\hat{i} + (N_2 - m_2 g \cos 20°)\,\hat{j}$

4) 2nd Newton's Law for each object. $\vec{F}_{net} = m \cdot \vec{a}$

$\vec{F}_{net_1} = m_1 \cdot \vec{a}$ $\begin{cases} T - m_1 g \sin 60° = m_1 a \;(1) \\ N_1 - m_1 g \cos 60° = 0 \end{cases}$

$\vec{F}_{net_2} = m_2 \vec{a}$ $\begin{cases} m_2 g \sin 20° - T = m_2 \cdot a \;(2) \\ N_2 - m_2 g \cos 20° = 0 \end{cases}$

5) Solve for a using equations (1) & (2):

$$T - m_1 g \sin 60° = m_1 \cdot a \quad (1)$$
$$m_2 g \sin 20° - T = m_2 \cdot a \quad (2)$$

If masses are known, this is a system of 2 equations with 2 unknowns T & a.

Let's eliminate T: $T = m_1 g \sin 60° + m_1 \cdot a$

$$\rightarrow m_2 g \sin 20° - m_1 g \sin 60° - m_1 \cdot a = m_2 \cdot a$$

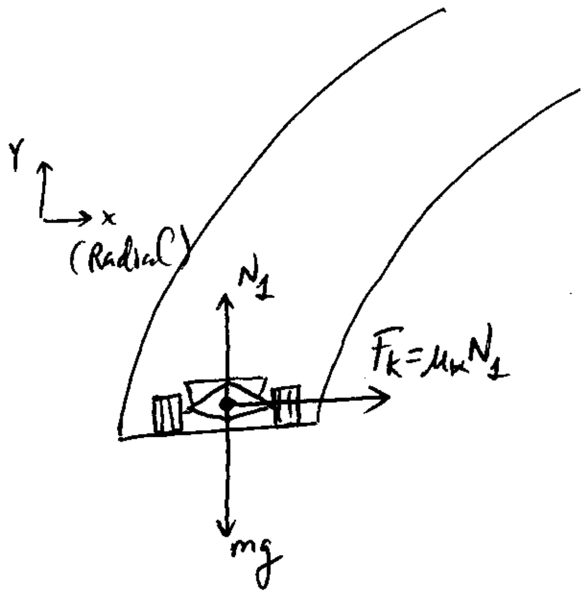
$$\Rightarrow \boxed{a = \frac{(m_2 \sin 20° - m_1 \sin 60°) \cdot g}{m_1 + m_2}}$$

Analysis:

- $a = 0$ when $m_2 \sin 20° = m_1 \sin 60°$ or $\frac{m_2}{m_1} = \frac{\sin 60°}{\sin 20°}$
  $\rightarrow$ no motion $\rightarrow$ system in static equilibrium.
- $a > 0$ (m_1 uphill & m_2 downhill, as assumed)
  $\frac{m_2}{m_1} > \frac{\sin 60°}{\sin 20°}$
- $a < 0$ (m_1 downhill, m_2 uphill, opposite to assumed)
  $\frac{m_2}{m_1} < \frac{\sin 60°}{\sin 20°}$

Forces & Uniform Circular Motion:

Flat race track



$$\vec{F}_{net} = \mu_k N_1 \hat{i} + (N_1 - mg)\hat{j}$$

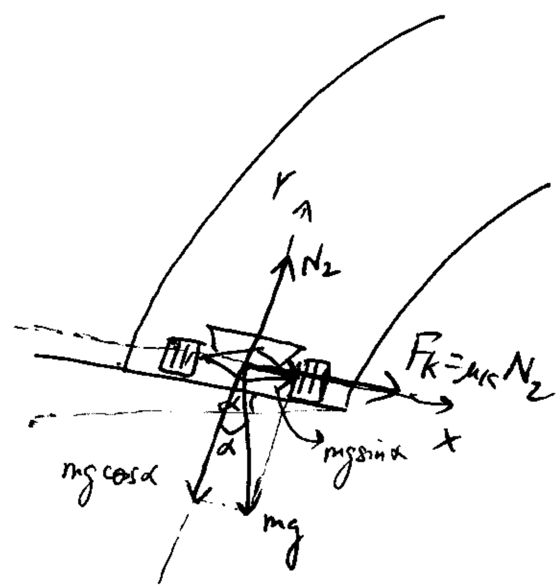
$$\vec{F}_{net} = m\cdot\vec{a} = m\cdot\frac{v^2}{R}\hat{i}$$

$$\begin{cases} N_1 - mg = 0 \\ \mu_k N_1 = m\frac{v^2}{R} \\ \mu_k \cancel{m} g = \cancel{m}\frac{v^2}{R} \end{cases}$$

UCM: object follows circular trajectory at constant speed, velocity vector has constant magnitude but changing direction due a radial acceleration $a = \frac{v^2}{R}$ (R: radius of curvature)

→ $v_F = \sqrt{\mu_k g R}$ (flat track)

Slanted race track



$$\vec{F}_{net} = (\mu_k N_2 + mg\sin\alpha)\hat{i} + (N_2 - mg\cos\alpha)\hat{j}$$

$$\vec{F}_{net} = m\cdot\vec{a} = m\frac{v^2}{R}\hat{i}$$

$$\begin{cases} N_2 = mg\cos\alpha \\ \mu_k \cancel{m} g\cos\alpha + \cancel{m} g\sin\alpha = \cancel{m}\frac{v^2}{R} \end{cases}$$

$$v_S = \sqrt{gR(\mu_k\cos\alpha + \sin\alpha)} \quad \text{(slanted track)}$$

$$\frac{v_S}{v_F} = \sqrt{\frac{\mu_k\cos\alpha + \sin\alpha}{\mu_k}}$$

~~Flat~~: $v_S > v_F$ if $\mu_k\cos\alpha + \sin\alpha > \mu_k$

$$\frac{\sin\alpha}{1-\cos\alpha} > \mu_k$$

This allows race car to turn at a higher speed!

Example: $\alpha = 20^\circ$; $\mu_k = 0.2$

$$\frac{\sin 20^\circ}{1-\cos 20^\circ} = 5.67 > 0.2$$

$$\frac{v_S}{v_F} = \sqrt{\frac{0.2 \times \cos 20^\circ + \sin 20^\circ}{0.2}} = 1.63$$

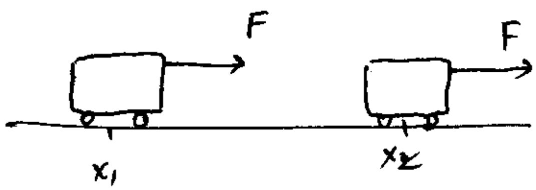
Ch 6 Work, Energy, and Power

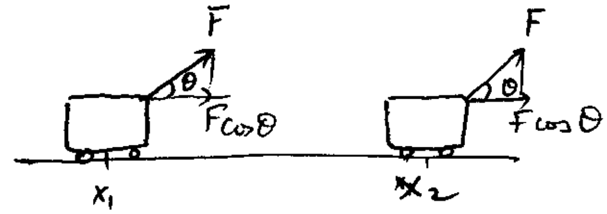
Work: $\vec{F} \cdot \Delta\vec{r}$

Applied force vector

scalar product (of vectors)

displacement vector





Work done: Force in direction of motion × displacement

$$\text{Work} = F \cdot \Delta x = F \cdot (x_2 - x_1)$$

SI unit: $N \cdot m \equiv J$ (Joule)

Here force in direction of motion is $F\cos\theta$

$$\text{Work} = F\cos\theta \cdot \Delta x = F\cos\theta\,(x_2 - x_1)$$

The y-component of the force applied $F\sin\theta\,\hat{j}$ is not doing any work: $\Delta y = 0$

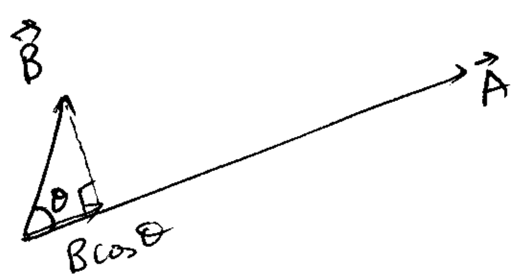
$\Rightarrow F\sin\theta \cdot \Delta y = 0$

Scalar product of vectors:

It's a product of two vectors that is a number.

A scalar is a number, such as: time, mass, energy, work etc.

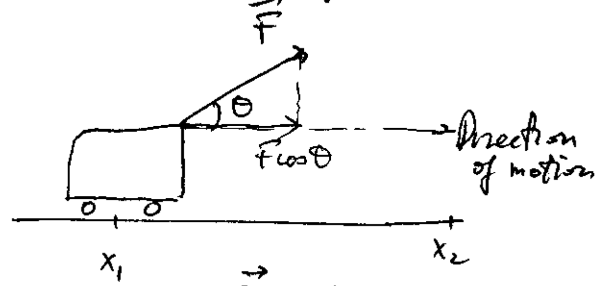
Scalar product of two vectors $\vec{A}$ & $\vec{B}$:



$$\vec{A} \cdot \vec{B} = A\,\underbrace{B\cos\theta}_{\text{projection of } \vec{B} \text{ onto } \vec{A}}$$

$$\vec{F} \cdot \Delta\vec{r} = \underbrace{F\cos\theta}_{\text{Projection of } \vec{F} \text{ onto direction of motion}} \cdot \Delta r$$

In the previous example: $\Delta\vec{r} = \Delta x\,\hat{i}$:



$\vec{\Delta r} = \Delta x\,\hat{i} = (x_2 - x_1)\hat{i}$

Work $= \vec{F}\cdot\Delta\vec{r} = F\cos\theta\cdot\Delta x$

In general, if $\Delta\vec{r} = \Delta x\,\hat{i} + \Delta y\,\hat{j}$:

$$\text{Work} = \vec{F}\cdot\Delta\vec{r} = (F\cos\theta\,\hat{i} + F\sin\theta\,\hat{j})\cdot(\Delta x\,\hat{i} + \Delta y\,\hat{j})$$

$$\left.\begin{aligned}\hat{i}\cdot\hat{i} &= 1\cos 0\ 1 = 1 \checkmark\\ \hat{j}\cdot\hat{j} &= 1\cdot\cos 0\cdot 1 = 1 \checkmark\\ \hat{i}\cdot\hat{j} &= 1\cdot\cos 90\cdot 1 = 0\\ \hat{j}\cdot\hat{i} &= 0\end{aligned}\right\}\ \boxed{\text{Work} = F\cos\theta\cdot\Delta x + F\sin\theta\cdot\Delta y}$$

So far $\vec{F}$: force applied is constant during the displacement $\Delta\vec{r}$. If it is changing during the displacement:

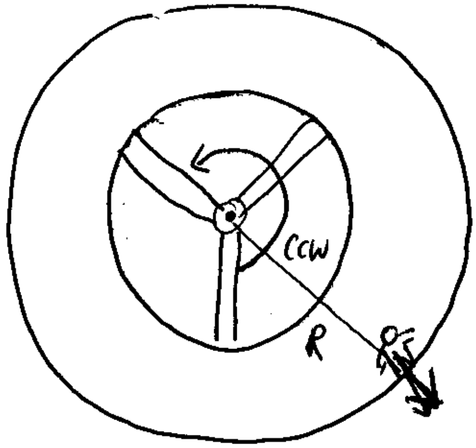
$$\text{Work} = \int_{\vec{r}_1}^{\vec{r}_2} \underbrace{\vec{F}}_{\text{Force applied}}\cdot\underbrace{d\vec{r}}_{\text{infinitesimal displacement vector}}$$

Example: <u>work done by a spring</u> : $F = -k\Delta x$ or $-kx$ (if measured w.r.t. natural length)

$$\text{Work} = \int_0^x -kx\cdot dx = -k\int_0^x x\,dx = -\tfrac{1}{2}kx^2$$

pulling it from natural length $(x=0)$ to ~~pos~~ elongation x : in this case spring is receiving work (work done by us)

5.36



Space station, view from above: it rotates in CCW direction at constant speed v

Astronaut's mass: m

$R = 225\,m$

$$\cancel{m}\frac{v^2}{R} = \cancel{m}g$$

$$v = \sqrt{gR} = 46.9\,m/s$$

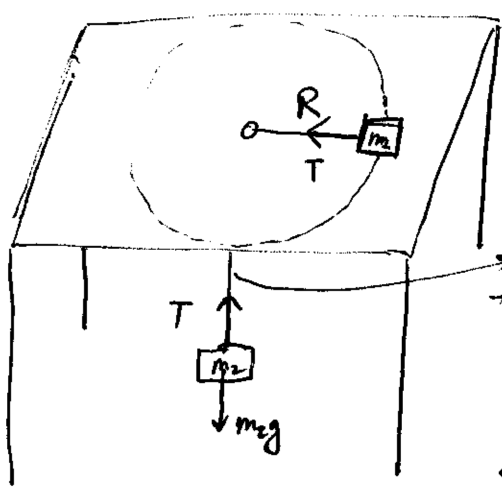
Speed: in revolution per min.? → (rpm)

1 rev is $2\pi R = 2\pi \cdot 225\,m$

$$46.9\,\frac{\cancel{m}}{\cancel{s}} \cdot \frac{1\text{ rev}}{2\pi \cdot 225\,\cancel{m}} \cdot \frac{60\,\cancel{s}}{1\text{ min}} = 1.99\text{ rpm}$$

5.37

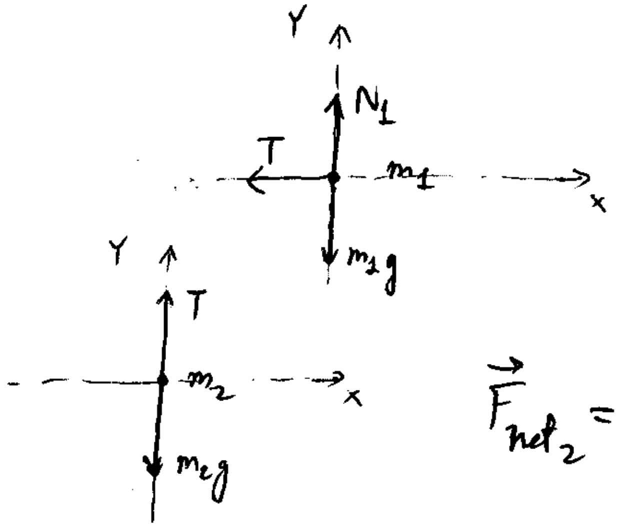
1)



- massless string → same tension throughout string.
- m_2 is stationary → $a = 0$
- Tension $\begin{cases} \to \text{holds } m_2 \text{ stationary} \\ \to \text{holds } m_1 \text{ in a UCM} \end{cases}$
- Frictionless table

2) Convenient coord-system for each object $\begin{cases} m_1 & Y \uparrow \to x \\ m_2 & Y \uparrow \to x \end{cases}$

3)



$$\vec{F}_{net_1} = -T\,\hat{i} + \underbrace{(N_1 - m_1 g)}_{0}\hat{j}$$

$$\vec{F}_{net_2} = 0\,\hat{i} + \underbrace{(T - m_2 g)}_{0}\hat{j}$$

4) 2nd Newton's law for each object:

$$\rightarrow \vec{F}_{net_1} = \underbrace{-T\,\hat{i}}\ = m_1 \cdot \vec{a}_1 = \underbrace{m_1 \cdot \frac{v^2}{R}(-\hat{i})}$$

$$\rightarrow \boxed{T = m_1 \cdot \frac{v^2}{R}}$$

$$\rightarrow \vec{F}_{net_2} = 0 \rightarrow \boxed{T = m_2 g}$$

$$m_2 g = m_1 \frac{v^2}{R}$$

5) a) Solve for T → $T = m_2 g$

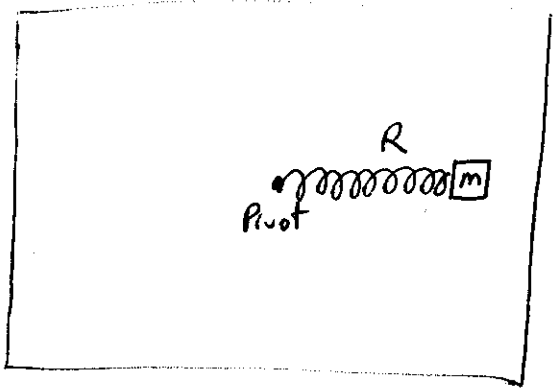
b) Period of circular motion: (also called T!): time to complete one circumference $2\pi R$:→ $\dfrac{2\pi R}{v} = \dfrac{2\pi R}{\sqrt{\frac{m_2}{m_1} g R}}$

$$m_2 g = m_1 \frac{v^2}{R} \rightarrow v = \sqrt{\frac{m_2}{m_1} g R}$$

Period: $T = 2\pi \sqrt{\dfrac{m_1 R}{m_2 g}}$

5.62

1)



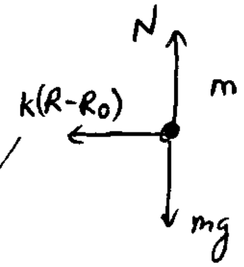
- View from above
- Frictionless table
- Spring has a natural length of $R_0 = 18$ cm
- $K = 150 \frac{N}{m}$; $m = 2.1$ kg

When m undergoes UCM (with $v = 1.4 \frac{m}{s}$) it needs a force towards the center of curvature, this force is provided by the spring. By the 3rd Newton's law, m will pull on the spring with a same force in opposite direction (away from center) → spring get stretched to a new length R.

→ Question → R?

2) Convenient coord. system for m : $Y \uparrow$, $\rightarrow x$

3)



$$\vec{F}_{net} = -k(R-R_0)\hat{i} + \underbrace{(N-mg)}_{0}\hat{j}$$

spring force is only proportional to the stretch from the natural length.

4) 2nd Newton's law for m:

$$\vec{F}_{net} = m \cdot \vec{a}$$

$$-k(R-R_0)\hat{i} = m \cdot \frac{v^2}{R}(-\hat{i})$$

$$k(R-R_0) = m\frac{v^2}{R}$$

5) Solve for R:

$$kR^2 - kR_0R - mv^2 = 0$$

$$150R^2 - \underbrace{150 \cdot 0.18}_{27} R - \underbrace{2.1 \cdot 1.4^2}_{4.12} = 0$$

$R_0 = 18\text{cm} = 0.18\text{m}$

$$R = \frac{27 \pm \sqrt{27^2 + 4 \cdot 150 \cdot 4.12}}{300} = \begin{cases} + \rightarrow 0.279\,m \\ - \text{ gives a negative } R \rightarrow \text{doesn't make sense} \end{cases}$$

$$\boxed{R = 0.279\,m}.$$

$\boxed{\text{Energy:}}$ same dimension and so units as Work

For motions → Kinetic energy or K.E.:

Starting with 2^{nd} Newton's Law: $\boxed{\vec{F}_{net} = \frac{d\vec{p}}{dt} = m \cdot \frac{d\vec{v}}{dt}}$

m is constant

Work applied by net force on the object to change the motion of an object of mass m:
(between initial position $\vec{r}_1$ & final position $\vec{r}_2$)

$$\hookrightarrow \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}_{net} \cdot d\vec{r} = m \int_{\vec{r}_1}^{\vec{r}_2} \frac{d\vec{v}}{dt} \cdot d\vec{r} = m \int_{\vec{r}_1}^{\vec{r}_2} d\vec{v} \cdot \underbrace{\frac{d\vec{r}}{dt}}_{\vec{v}}$$

scalar product

$$= m \int_{\vec{r}_1}^{\vec{r}_2} \vec{v} \cdot d\vec{v} = m \int_{\vec{r}_1}^{\vec{r}_2} v\, dv = \frac{1}{2} m v^2 \Big]_{\vec{r}_1}^{\vec{r}_2}$$

Scalar product is commutative

in linear motion $\vec{v} \parallel d\vec{v}$

$$= \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2 = KE_2 - KE_1$$

→ Work applied to change motion $=$ K.E. $= \frac{1}{2} m v^2$.

$\boxed{\text{Power:}}$ P : work or energy per unit time → SI unit: $\frac{J}{s}$

Also $\frac{J}{s}$ is called W (Watts)

Car: when you start it: $KE_1 = 0$; when it runs at 70 mph → KE_2

However if you reach KE_2 in less time → need more power!

Average Power: $\overline{P} = \dfrac{\Delta \text{Work}}{\Delta t}$

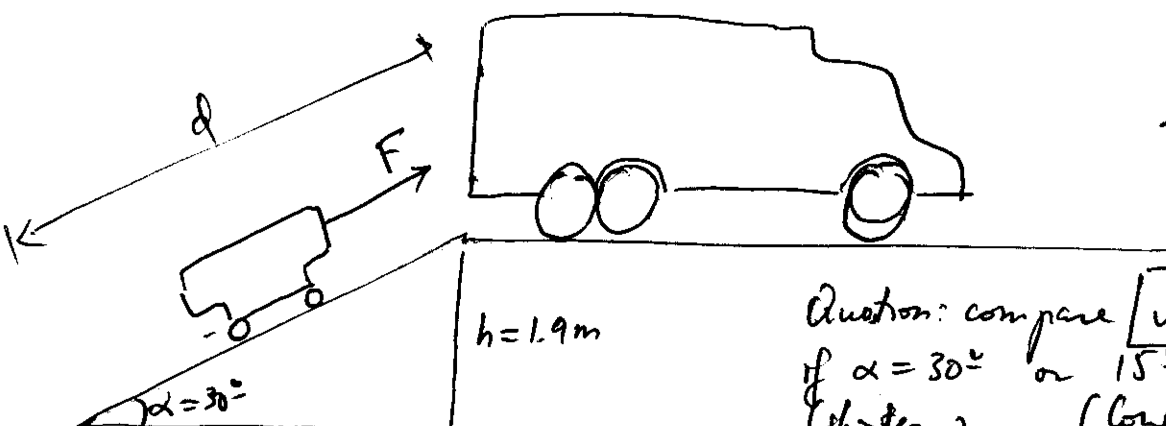
Instantaneous Power $P = \dfrac{d\,\text{Work}}{dt}$

Power & velocity: $P = \dfrac{d\,\text{Work}}{dt} = \dfrac{d(\vec{F}\cdot\Delta\vec{r})}{dt}$

$$= \vec{F}\cdot\underbrace{\frac{d\,\Delta\vec{r}}{dt}}_{\vec{v}} = \boxed{\vec{F}\cdot\vec{v}}$$

$\vec{F}$ is constant

Application: Work & Force in moving a piano: load a piano onto a truck.



$m = 460$ kg
$\mu_k = 0.62$

Question: compare $\boxed{\text{work done}}$ if $\alpha = 30°$ or $15°$ (same $h = 1.9$m)?
(shorter ramp) (longer ramp)

We apply a force F to move it up the ramp:

$$\text{Work} = F\cdot d = F\cdot\frac{h}{\sin\alpha}$$

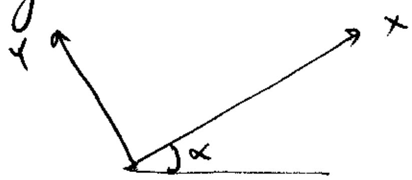
d ↓ length of ramp

$\dfrac{h}{d} = \sin\alpha$

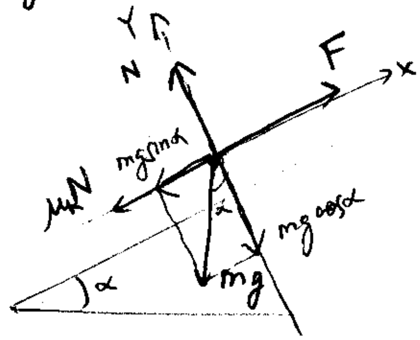
$h = 1.9$m
$\alpha = 15°$ or $30°$
Need to find F!
↓
5 step strategy.

1) Sketch ✓.

2) Convenient coord. system:



3) FBD for piano:



$$\vec{F}_{net} = (F - \mu_k N - mg\sin\alpha)\hat{i} + (N - mg\cos\alpha)\hat{j}$$

4) 2nd Newton's Law for piano: $\vec{F}_{net} = m \cdot \vec{a} = 0$

Minimum: moving it up with only constant speed $\rightarrow \vec{a} = 0$

$$\left\{ \begin{array}{l} F = \mu_k N + mg\sin\alpha \\ N = mg\cos\alpha \end{array} \right.$$

5) $\boxed{F = mg(\mu_k \cos\alpha + \sin\alpha)}$

$\rightarrow$ Work done $= F \cdot \frac{h}{\sin\alpha} =$

Longer ramp ($\alpha = 15°$) $= mgh \frac{\mu_k\cos\alpha + \sin\alpha}{\sin\alpha}$

$= 460 \cdot 9.81 \cdot 1.9 \frac{0.62 \cdot \cos 15 + \sin 15°}{\sin 15°}$

$= 28.5\,kJ$

Shorter ramp ($\alpha = 30°$)

$= 460 \cdot 9.81 \cdot 1.9 \frac{0.62\cos 30 + \sin 30}{\sin 30°}$

$= 17.8\,kJ$

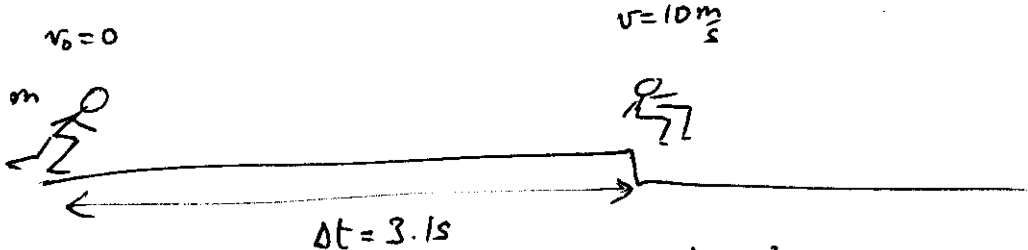
Steeper slope ($\alpha = 30°$) $\rightarrow$ less work!

Normally we prefer to do it at a smaller angle! Why?

Force applied (minimum required) $= \begin{cases} \alpha = 15^{\circ} : & F = 460 \cdot 9.81 (0.62 \cdot \cos 15^{\circ} + \sin 15^{\circ}) \\ & \quad = 3.88\,kN \\ \alpha = 30^{\circ} & F = 4.68\,kN \end{cases}$

(a steeper ramp require less work but also a higher minimum force applied!)

6.38 $\qquad\qquad m = 75\,kg$



$$\underline{P}\ ? = \frac{\text{Work}}{\text{time}} = \frac{\Delta KE}{\text{time}} = \frac{\frac{1}{2}mv^2 - 0}{\text{time}} = \frac{\frac{1}{2} 75 \cdot 10^2}{3.1} = 1.21\,kW$$

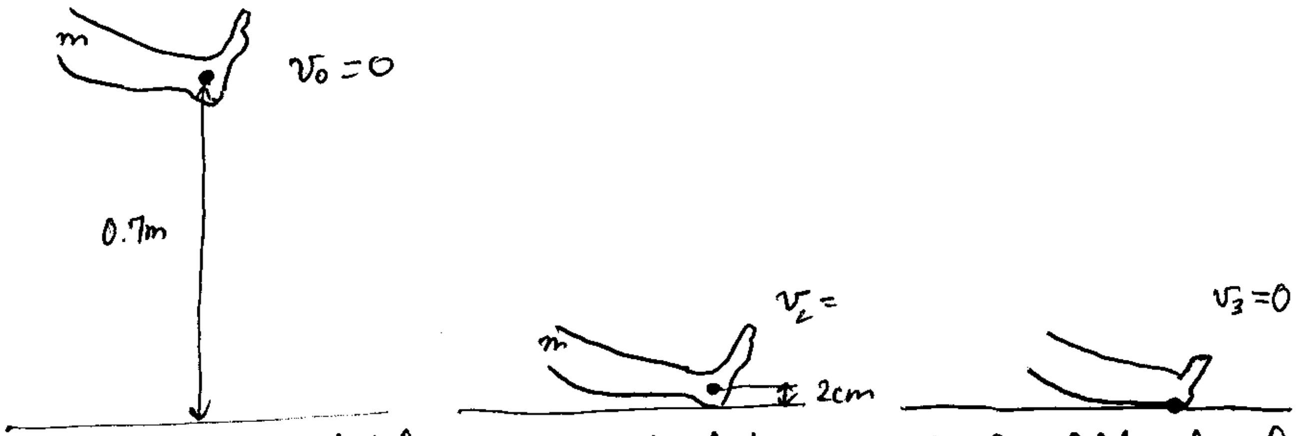
<u>Cars & trucks</u> ; H.P. ("Horse Power") $\quad 1\,H.P. = 746\,W$

$$\underline{P}_{jumper} = 1.21\,kW \frac{1\,HP}{0.746\,kW} = 1.6\,HP.$$

6.81 Similar to dropping an egg: 2 parts free fall $\begin{cases} \text{1) Const. accel. until almost touching the ground} \\ \text{2) Crashing until completely stopped (const. decel), very quick, where damages happen!} \end{cases}$

3 Snapshots to describe the 2 parts of the free fall:

$m = 8\,kg$, falling off a stretcher $\rightarrow v_0 = 0$



① Falling off stretcher

② Just about to touch the ground

③ Completely stopped (Center of mass of foot at ground level)

constant accel. or free fall

Stopping distance (vertical) is 0.02 m
Constant deceleration

$KE_1 = 0$ $\qquad KE_2 = \frac{1}{2} m v_2^2 \qquad KE_3 = 0$

Building up KE from ① to ② during time Δt

Same KE is gone from ② to ③ in very short time! into leg (bones, tissues, etc.)
$\downarrow$
Damage!

Want to calculate the stopping force F_{stop} (to see if it is 80N or much more)

Alternative #1: use work/energy:

1 → 2 Find energy acquired by leg during free fall:

Alternative a) $KE_2 - KE_1 = \frac{1}{2} m v_2^2$

Alternative b) Work done on leg by force of gravity:

$$Work = F \cdot h = mgh$$

2 → 3 This energy is gone during the stopping distance of 0.02m

$$mgh = F_{stopping} \cdot 0.02m \rightarrow F_{stop} = \frac{mgh}{0.02m} = \frac{8 \cdot 9.81 \cdot 0.7}{0.02}$$

$$\boxed{F_{stop} = 2744 N}$$

Alternative #2: use Kinematic equations & Newton's Law:

1 → 2 Find v_2: constant accel.

$$\frac{v_2^2 - 0^2}{h} = 2 \cdot g \rightarrow v_2 = \sqrt{2 \cdot g \cdot h}$$

$$= \sqrt{2 \cdot 9.81 \cdot 0.7}$$

$$= 3.7 \frac{m}{s}$$

2 → 3 const. decel. a

$$\frac{0^2 - v_2^2}{d_{stop}} = -2a \rightarrow a = \frac{v_2^2}{2 \cdot d_{stop}}$$

$$= \frac{3.7^2}{2 \cdot 0.02}$$

$$= 343.35 \frac{m}{s^2}$$

(deceleration!)

$$\boxed{F_{stop} = m \cdot a = 8 \cdot 343.35 = 2774 N} \gg 80N!$$