Ch. 5 Newtonian Physics

Fairly long conceptual introduction, but don't turn off your mind — or else you'll wonder the whole semester why nothing makes any sense

There are two key aspects of this course

1) Newtonian physics

2) the energy concept.

which we start now

which we introduce later into Newtonian physics, but it is more general and is all through physics

and actually most people have a some understanding of it already.

A few general words of intro

1) Physics — science of pattern motion to be brief → for the rest we must dive in.

2) Newtonian physics has a number of components.

— time & 3-d Euclidean space

an assumed background

~~actually not embedded in Newtonian physics~~

People used astronomical clocks early (lunar) year ... Newtonian physics ... fairly regular clocks

... this ... to count time

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Time we count
using oscillatory
devices (clocks)
that obey Newton's laws
and according to
those laws oscillate
with constant periods
ideally.

People told time before Newton of course using mainly Astronomical clocks justified - how could anyone know each day & year is of the same length (nearly) without a physical theory to say that it had to be so

Newtonian Physics justified these, by theoretical showing they should indeed be regular

b) Inertial frames
of reference

c) Newton's 3 laws
of motion.

d) Force laws independent of Newton's 3 laws

e) mass — measure of resistance to acceleration

all these components
fit together to make
the whole system
— and except for 3-d
Euclidean space

it's hard to

define them except in reference to each other.

— the components don't have a completely separate existance (except 3-d Euclidean space)

rhetorical questions
— what would mass mean without force?
— what would the 2nd law mean with force laws?

You have to accept *Newtonian physics* more or less as a package → the components together make sense → but not apart.

— And accepted as a whole *Newtonian physics* works

— It's an outstandingly useful ~~formul~~ theory

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from a vast realm
of applications.

It (Newton physics) was once thought
to be fundamentally true or at least possibly so
that is exactly true and
without any way to
explain it in terms of
more fundamental physics.
(or anything else)

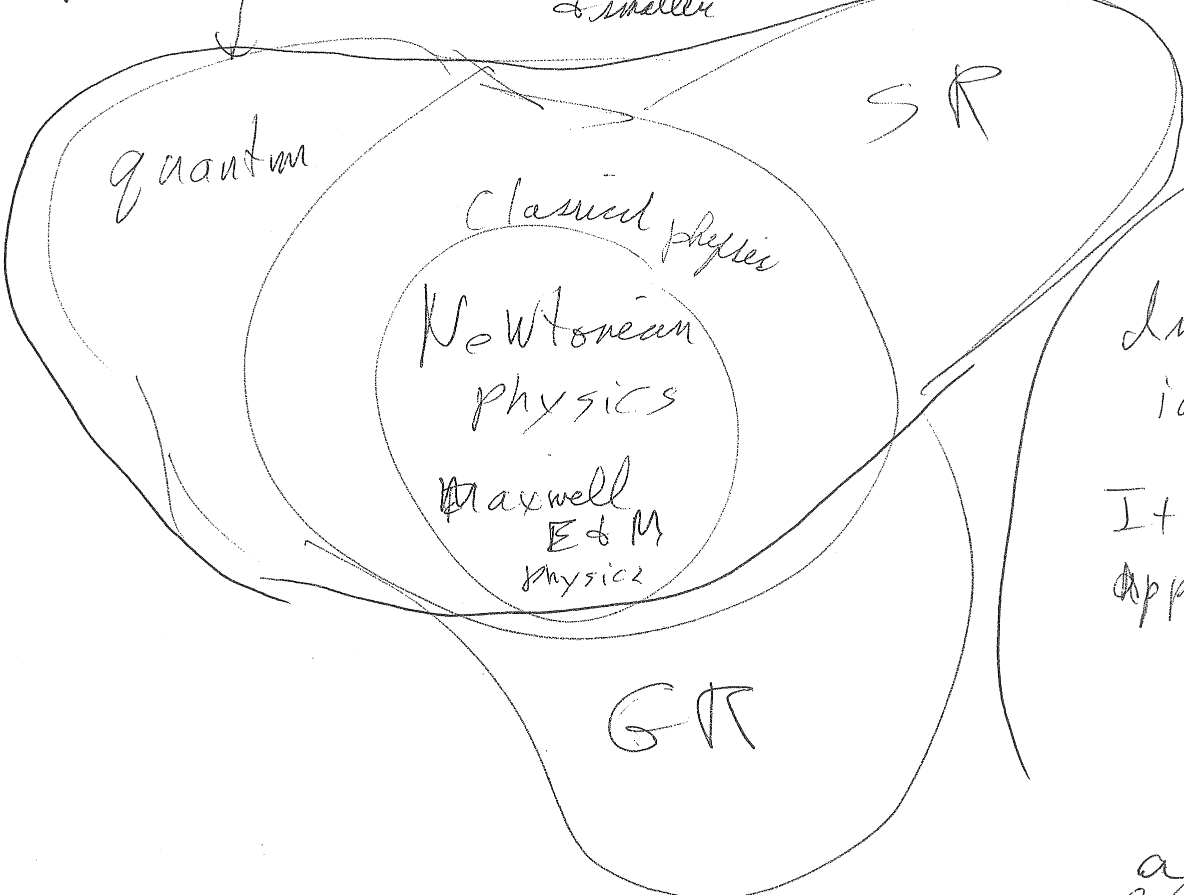
We know know it isn't
fundamentally true.

At the atomic level one need
quantum mechanics
At speeds approaching that of
light one need
special relativity.
For strong gravity and the cosmos
(black holes)

as a whole, one needs GR, general relativity

Venn diagram?

microscopic (which physics means atomic & molecular & smaller) ⟶ macroscopic everything above. } No sharp line.



In my idiosyncratic jargon. It is a true approximate theory

– Newtonian physics is ~~the~~ a limiting form of these other theories.

⟶ Which have not been reconciled yet.

GR stands out.

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No consensus theory exists on how to unify it with QM.

We hope one day to have a <u>theory of everything</u>

TOE

a true <u>fundamental physics</u>

that explains all physics (which is science of matter & motion to be brief)

— Maybe that day is not far off.

— or maybe it is.

<u>Omit said before?</u>

Personally I don't think TOE is a good name since it's not <u>theory of everything</u> since physics isn't everything emergent principles (WIK)

trivial example

- chess game
- the board and pieces are physical objects, but the rules are arbitrary human constructs.
- you could imagine chess in another realm of physics

- ~~less trivial~~ → whatever are the

(a) rules of consciousness

c) rules of logic

→ our brains are obey our physics.

→ but one can imagine some other realm of physics in which consciousness arises.

- works as a mechanism on computers
- for microbes
- ~~all sci~~
- almost all scientists adhere to it

- (b) Darwin evolution → happen in other realms.

§ 4.2 Force concept

- push or pull seems up a lot.
- more deeply ~~it~~ force is the cause of accelerations

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~~in~~ Newton's 2nd law

which we'll get to by ~~&~~ by.

Cause of deformation of bodies too I'd say.

Forces are vector quantities — they have magnitude & direction

All uses are consistent with this

→ There are many kinds of forces.

$\underset{\sim}{F} = (F_x, F_y)$ in 2-d

– but only 4 fundamental ones

1) ~~Electromagnetic~~

which actually ~~is~~ — all forces in the macro-world except gravity

are special manifestations of the EM force

They are myriad of them and are given special names to indicate their special nature & use.

Tension force, friction, Normal force, air resistance, ...essive force, linear force, electrostatic force, magnetic force, | list goes on and on — many special purpose names exist

2) Gravity

3) strong nuclear

4) weak nuclear

outside of Newtonian physics.

— actually 1,3,4
have sort of been unified
— shown as aspects of the same thing in ~~the~~ the most fundamental modern theory given the blasé name the standard model.

Gravity remains the hold out, but we have hopes bringing it into unity.

~~Anoth~~ Another important classication of forces applies to the macro-world { in physics anyone would do well above the atomic level.

1) Contact forces
→ force exists just where bodies touch
~~all~~ most common manifestations of EM force are of this kind.

2) field forces (or body forces) — they act at a distance
— gravity
— but also the long range

5-10) electrostatic force
→ paper scraps demo.
— magnetic force.

At the microlevel {atomic level and below
all forces are field forces.
in fact,
— but at the macrolevel,
the approximation of ideal
~~of~~ contact force is very
useful.

~~For~~ For field forces one
~~often talk~~ thinks of
the field as emanating
from a body and the
field causes the force on
other bodies
→ we use electric, magnetic
and gravitational fields.

Inertial frames are a special class of frames not accelerated with respect to each other.

Newton's laws of motion are referenced ~~defined~~ relative to inertial frames

(Newton's laws are just as valid in all frames of reference, but not referenced to ~~them~~ unless you introduce fictitious forces (inertial forces) to fix ~~the~~ ~~[illegible]~~ things up → we'll see how to do this as we go along.

Newton himself thought the fixed stars defined the basic inertial frame.

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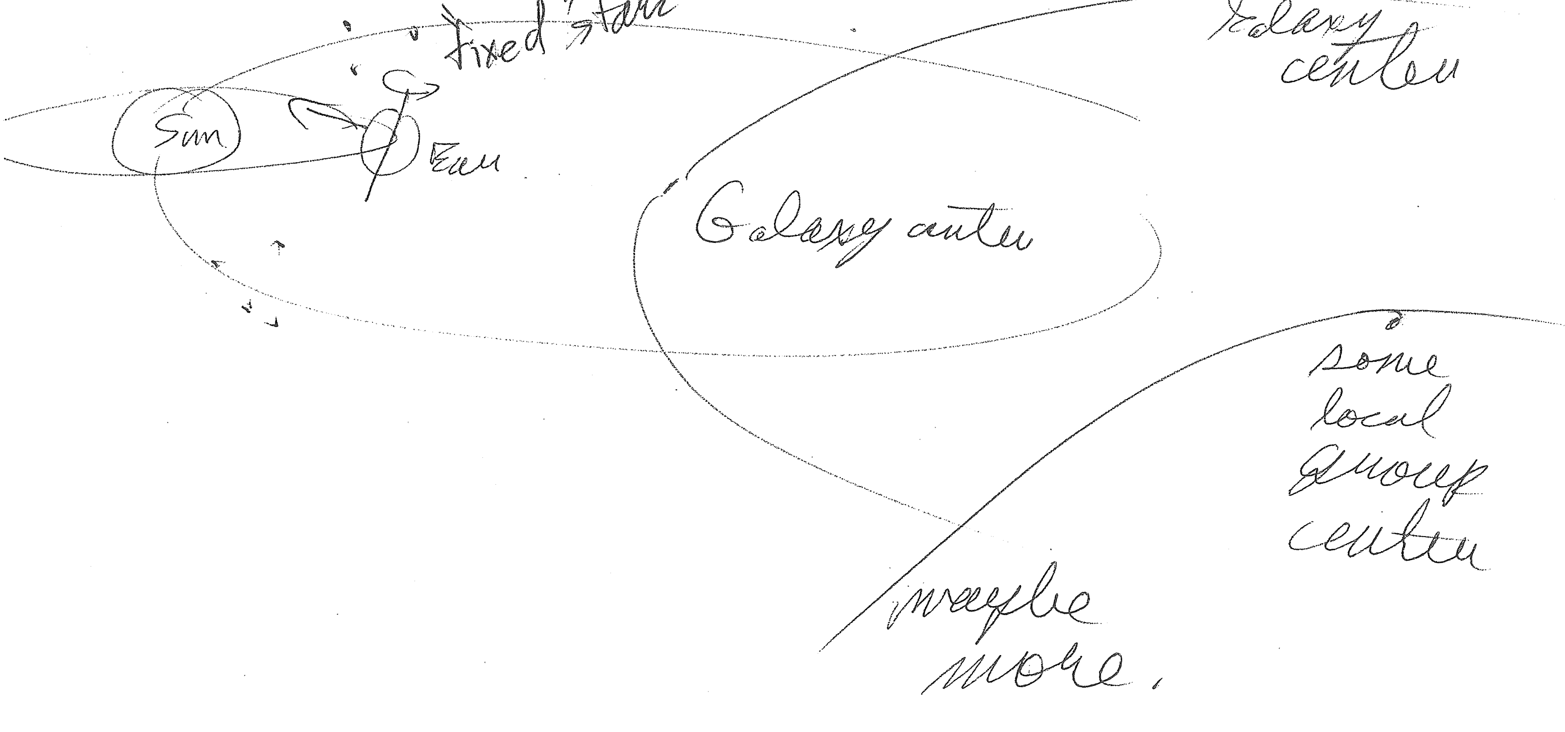
But the "fixed stars" of his day are not fixed.

— they ~~rotate~~ ~~aro~~ orbit in a complex way the Galaxy center.

accelerated motion since directions change

— the Galaxy has an orbit too in the local group of galaxies

Of course the Earth isn't exactly inertial — ~~it~~ rotates on it's axis and revolves around the Sun that revolves around the Galaxy center



In fact all macroscopic <u>physical</u> matter bodies we know of are <u>NOT</u> exactly inertial frames.

— but most of them are to some approximation.

— The Earth is inertial enough for most purposes — not all.

- long range gunnery — air & ocean currents must account for the acceleration of the Earth's surface

— What is the <u>basic inertial frame</u>

→ well in modern thinking there is no one basic one.

→ all frames participating in mean expansion of universe are believed to be true inertial frames → but almost no ~~body~~ matter is unaccelerate with respect to these since they almost all rotate.

→ And we can by astronomical measurements measure motion

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with respect to them.
(but we won't go into how here)

Newton's 1st law } different ways of stating it. I prefer a more conventional one to Serway.

— A ~~body~~ object ~~acted on~~ on which there is no ~~no~~ net force

is unaccelerated with respect to all inertial frames

— i.e., it is either in straight line motion or at rest depending on the inertial frame of reference.

Serway ~~likes~~ by "no forces at all".

— But "no forces" to my thinking is just a special case of "no net Force"

but not gross
there are no gross forces

$\underset{\sim}{F}_{net} = \sum \underset{\sim}{F}_i$ } sum of all particular force

or total or resultant!

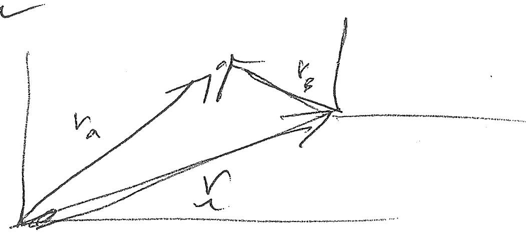
for the summed quantity

~~Forces~~

1st law abbreviated } $\underset{\sim}{F}_{net} = 0$ gives $\underset{\sim}{a} = 0$ relative to all inertial frames.

Recall the Galilean transformations

$$\underset{\sim}{r}_B = \underset{\sim}{r}_a - \underset{\sim}{r}$$



$$\underset{\sim}{v}_B = \underset{\sim}{v}_a - \underset{\sim}{v}$$

$$\underset{\sim}{a}_B = \underset{\sim}{a}_a$$

if $\underset{\sim}{a} = \frac{d\underset{\sim}{v}}{dt} = 0$ } the frames are not relatively accelerated, as is true for all inertial frames

So if $\underset{\sim}{a} = 0$ for an object in one inertial frame it's $\underset{\sim}{a} = 0$ in all of them

§5.4 2nd law

} skip ~~§~~ §5.3 on mass for a moment and incorporate mass as we go along { Combine with §5.4

or "F = ma" is how we often call it.

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It's a vector law.

The mathematical statement is

$$\underset{\sim}{F}_{net} = m\,\underset{\sim}{a}$$

net force on an object
— Not any one force → the net force

mass of object
— a scalar property of the object that is it's resistance to acceleration

acceleration of object treated as a point mass
— later on we'll see this means acceleration of the object's center of mass.

If we write the formula,

$$\underset{\sim}{a} = \frac{\underset{\sim}{F}_{net}}{m}$$

$\underset{\sim}{a}$ points in direction of $\underset{\sim}{F}_{net}$

and $|\underset{\sim}{a}| \uparrow$ as $|\underset{\sim}{F}| \uparrow$

as $m \uparrow$, $|\underset{\sim}{a}| \downarrow$

"$F = ma$" is the connection between forces (causes of acceleration) and ~~kinematics~~ kinematics (description of motion).

Kinematics plus laws of motion and force laws is called dynamics

Mass is sometimes called
the quantity of matter

→ a sort of secondary definition
true in a sense

Say you had a lump of matter of
mass M all made of one kind of atom A

In QM theory every atom
is identical and has identical
mass → m_A say

∴ Number of atoms $= \frac{M}{m_a} \propto M$

So M gives you the number of atoms
→ a reasonable way to define
quantity of matter.

Mass can be directly measured
by applying known forces
(known from force laws)
and measuring $\underset{\sim}{a}$ ~~then~~

logically you could do this if you have a force known to be constant whatever its law,
— $m = \frac{|\underset{\sim}{F}|}{|\underset{\sim}{a}|}$ vary m and measured a

$$m = \frac{|\underset{\sim}{F}|}{|\underset{\sim}{a}|}.$$

But that takes

a minimal ~~knowledge~~ theory of the forces you are using.

but actually in most cases mass is measured by assuming the equivalence of mass (inertial mass) and gravitational mass which we'll discuss in a bit.

and then doing a comparison with some kind of scale (e.g., a balance scale)

both kinds of mass are just called mass since we believe them to be equivalent. A point we'll go into in a bit.

1st law is actually a consequence of the 2nd law: if $\underset{\sim}{F}_{net} = 0$, ~~then~~ $\underset{\sim}{a} = 0$ and so logically there are only 2 laws of Motion, but for historical and pedagogical reasons we define the 1st law as the 1st law. Actually Serway disagrees with this view it seems. But I think he's wrong. and so do others — like ~~my~~ the professor taught me intro physics — Carl Stayer. Matter of opinion.

Units

$$\underset{\sim}{F}_{net} = m \underset{\sim}{a}$$

$$m \leftarrow kg \qquad \underset{\sim}{a} \leftarrow \frac{m}{s^2}$$

$$\therefore [F] = kg \frac{m}{s^2} = N \quad \text{the newton.}$$

$1 \text{ Newton} \cong .2248 \text{ lb}$ of force in British units

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Actually physicists don't use the word Newton much except in teaching 1st year physics courses — It's just the MKS unit of force

$\cong \frac{1}{5}$ or $\frac{1}{4}$ it is in between awkwardly.

Mass is not weight

(kg) — an intrinsic property of object
— same wherever object is
— on Moon, Earth ~~J~~ Jupiter, empty space

(N) — is magnitude force of gravity on the object
— depends on ~~what the~~ gravitational field on object.

e.g., weights on lunar surface is $\frac{1}{6}$ of weights on Earth.

~~In~~ Cartesian components

Class mantra
Newton's 2nd law is always true and it's always true component by component.

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

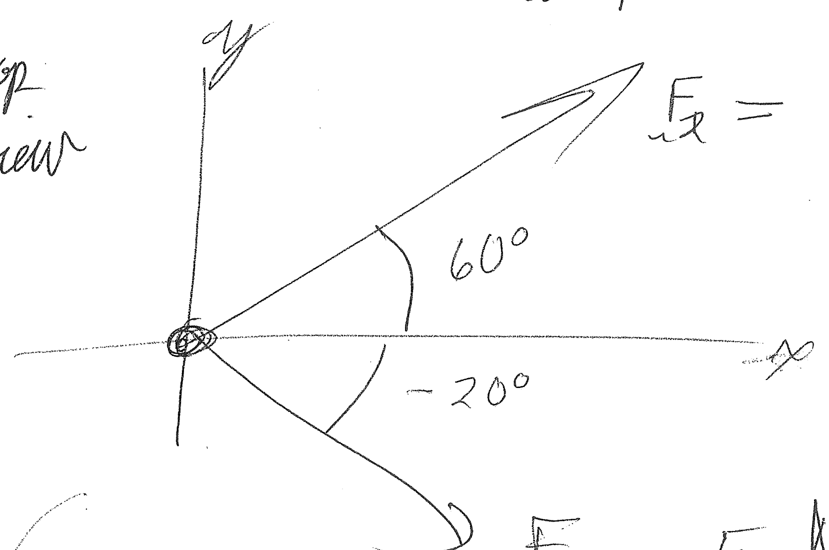
— although it's tedious
— breaking a force into components

5-20 is often how problems must be solved.

— Usually there is a convenient set of axes to make finding the components easy.

Ex 5.1 accelerating hockey puck (treated as a point mass) on frictionless ice
ideal ice.

Top view



$\underset{\sim}{F}_2 = 8.\,N$ at $60°$

$m = 3\,kg$

$\underset{\sim}{F}_1 = 5\,N$ at $-20°$

example of a free body diagram (FBD)

→ draw on forces exerted on the body.

If you start drawing those then you can easily confuse forces with ... forces.

Not the forces the body exerts (usually — there are exceptions to every rule)

If you start drawing those then it's easy to confuse yourself with canceling forces.

~~Ex~~ 5—21

Find $\underset{\sim}{a}$

$$\underset{\sim}{F}^{net} = m\,\underset{\sim}{a}$$

$$F_x^{net} = F_1 \cos\theta_1 + F_2 \cos\theta_2 = m\,a_x$$

$$\simeq \cancel{5} \cdot .94 + 8 \cdot .5 = .3\,a_x$$

$$a_x \simeq \frac{5 + 4}{.3} = \frac{F_1 \cos\theta_1 + F_2 \cos\theta_2}{m}$$

$$\simeq 30\ \mathrm{m/s^2}$$

$$a_y = \frac{F_1 \sin\theta_1 + F_2 \sin\theta_2}{m}$$

$$= \frac{\cancel{8} \cdot (-.34) + 8 \cdot .866}{.3}$$

$$= \frac{-1.7 + 7}{.3} \simeq 16\ \mathrm{m/s^2}$$

$$\therefore\ a = \sqrt{a_x^2 + a_y^2} = \sqrt{900 + 256}$$

$$\simeq 33\ \mathrm{m/s^2}$$

Ans 34 m/s, 30°

$$\theta = \tan^{-1}\left(\frac{16}{30}\right) \simeq \tan^{-1}\left(\frac{1}{2}\right) \simeq \frac{1}{2}\ \text{rad} = 30°$$

small angle approximation

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§5.5 Gravitational Force & Weight.

Without prescription for forces (force laws) F=ma would be rather useless or meaningless — you could only identify a force and its value by seeing acceleration. But then you couldn't calculate acceleration from forces.

~~Gravity~~ provides an important example of a force law

A general force law for gravity is

$$\underset{\sim}{F}_g = m \underset{\sim}{g}$$

gravitational force — Not net force

gravitational mass "the charge" of the gravitational force.

gravitational field — but specifying the gravitational field

in ~~particular special~~ general
~~cases in~~
~~takes~~ takes a lot of formalism.

But near the surface of
the Earth

$\underset{\sim}{g} \equiv g$ downward
to Earth's
~~center~~ center.

very nearly exactly
with $g = 9.8 \frac{N}{kg}$

$= 9.8\ m/s^2$

$g = 9.780 - 9.832$
equator   poles
— also
decreases
a bit
with altitude
and has
local variations.

But this
is only the acceleration
of an object if no other
forces act → i.e., it
is in free-fall.

We'll look at ~~the~~ more general
gravity cases in Ch. 13

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$$\underset{\sim}{F}_g = m\,\underset{\sim}{g}$$

gravitational mass

$$\underset{\sim}{F}^{net} = m\,a$$

inertial mass

$$m_{gr} = m_{in}$$

and so we usually don't distinguish the two.

but in <u>Newtonian physics</u> this equality is ~~just~~ a <u>coincidence</u>.

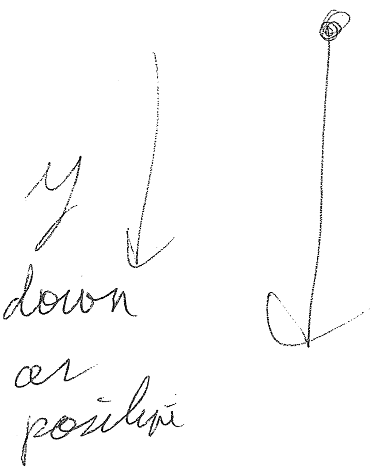
— people have tried very hard experimentally to find a difference, but none has been found.

if it exists it is very minute.

— in GR $m_{gr} = m_{in}$ is a

basic postulate

and so many like to think the equivalence is exactly true.



Just for an example say an object is only acted on by gravity (near Earth's surface)

$$F_{y_{net}} = m_{inertial}\, a_y$$

$$F_{y_{net}} = F_g = m_{gr}\, g$$ sign is positive for down

only gravity acts.

$$\therefore\ m_{in}\, a_y = m_{gr}\, g$$

$$a_y = \frac{m_{gr}}{m_{in}}\, g$$

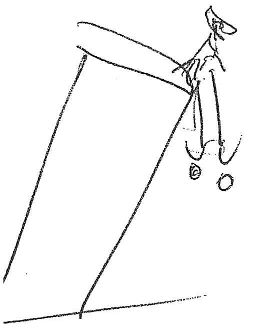
If $m_{gr} \neq m_{in}$, then ~~do~~ one would ~~think that~~ imagine that $\frac{m_{gr}}{m_{in}}$ would vary depending on the properties of the object.

5-26

and a_y would vary from g,

but to the best that

we can tell $m_{gr} = m_{in}$



and $a_y = g$ for free-fall

just as Galileo ~~believed~~

advocated ~ 1600.

We usually measure ~~gravitational~~ mass using gravity
in balance scales rather
than its acceleration

so were usually measuring grav. mass.

Weight $W = mg$ the magnitude
of the force
of gravity.

On the Earth's surface

g is almost constant

and so ~~to~~ good approximation

we can ~~treat~~ use W and mass

interchangeably for some purposes

like quantity of matter ~~[illegible]~~ purposes.

But weight is really

location ~~position~~ dependent.

on the Moon

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$$g_{moon} = .1654 \sim \frac{1}{6} g_{Earth}$$

$$W_{moon} \sim \frac{1}{6} W_{Earth}$$

but mass is the same.

As Serway points out
the lunar astronauts
wore support units $\sim$ 300 lb
on Earth.
$\sim$ 140 kg

— on Moon
$\sim$ 50 lb
still pretty
heavy

So the astronaut could ~~lift~~ the
units.

But when they accelerated
— ~~stay~~ starting or stopping
walking.

5-28 they had to exert~~s~~ horizontal forces needed to accelerate ~140 kg.

So moving on the Moon wasn't all that joyous (besides the lunar dust - regolith is slippery glassy grains)

People have carried heavy ~~pack~~ backpack loads know about the increased ~~the~~ inertia effect as well as increased ~~mass~~ weight.

§5.6 3rd Law

For every force there is an equal and opposite force

— the law of reaction.

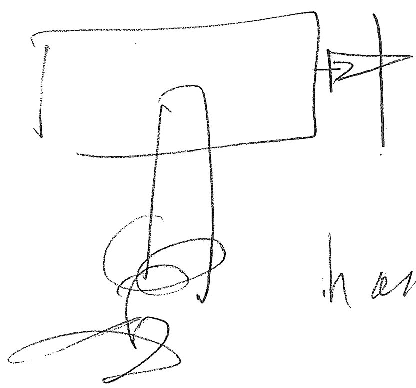
— Why don't the forces cancel and give us a world without

Actually this law isn't always true as stated even in classical physics (Go-8)

But there is a generalization that is always true. We don't need to worry about this complication acceleration.

— The equal & opposite forces don't have to be on the same object.

Ex



hammer exerts force on nail
nail exerts force on hammer.

Let's introduce another force (which is a manifestation of electromagnetic force)

— the **normal force**

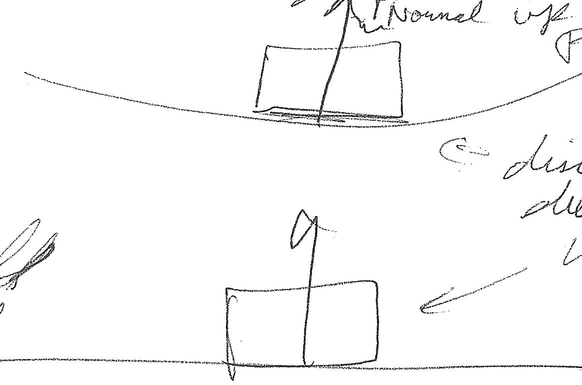
the force exerted by a a rigid surface perpendicularly outward ~~fr~~ from the surface when ~~the~~ the surface is pushed on

(What Normal means in this case.)

5-30

perpendicularly inward.

For a rigid surface ~~object~~ the distortion is small, but usually microscopic for a microscopic object.



from the distortion, one can in principle calculate F_{Normal} (and in practice)

But that is beyond our scope.

We assume ~~a~~ perfectly rigid surfaces for our normal force calculation

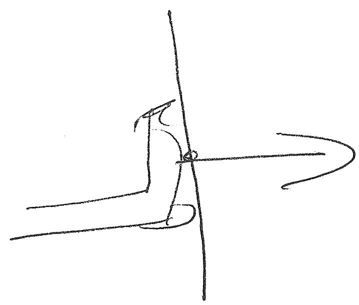
a simplifying idealization that works well.

But it means we have no intrinsic force law for the normal force

To calculate the normal force we must always use the 2^{nd} or 3^{rd} law

(which is a thing textbooks almost never explicitly mention.)
— They imagine the students will never notice — and they are right — it took me years to figure this out

Ex a

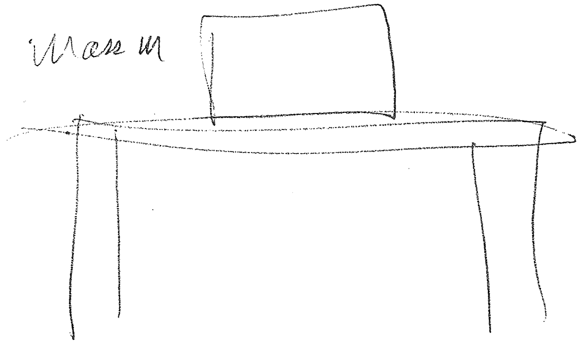


Push on wall with $\mathbf{F}_{push}$

- The wall pushes back with normal force $\mathbf{F}_N = -\mathbf{F}_{push}$

The 3^{rd} law tells us what $\mathbf{F}_N$ is.

Ex b Microwave oven sits on a table.



~~What~~ $\mathbf{a} = 0$ given

What are the forces on Microwave

— x - direction all are 0 $a_x = 0$

- in y - direction

$$F_y^{net} = F_g + F_N = ma_y = 0$$

$$\therefore \quad F_N = -F_g = -(-mg) = mg$$

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The 2nd law has given us $\underset{\sim}{F}_N = mg$ up (in this case.)

It is not a general formula, just a solution for this special (but very common case).

What is the 3rd law opposite force for force $\underset{\sim}{F}_g = mg$ down on the microwave?

Well Mg up on the Earth. (But the Earth doesn't notice much $F_y^{net} = mg = Ma_y$

$a_y = \frac{m}{M} g$

What is the 3rd law opposite force for $\underset{\sim}{F}_N$ normal up on microwave?

$M = 6 \times 10^{24}$ kg

$\underset{\sim}{F}_N$ normal down of microwave on Table.

The microwave alone is too small a perturbation to notice.

This assumes the microwave acts alone.
— Actually all kinds of bigger forces on Earth.
— gravity force of the Sun

§5.7 Some Application of Newton's laws

- we assume ~~objects~~ are particles
  doesn't mean small in this context, but rather ~~that~~ their structure can be neglected, and thus any rotation ~~or~~ and internal motion are neglected.

Tension force

- the force that ~~prevents~~ resists an object from being stretched

(Normal force ~~prevents~~ resists an object from being compressed)

like the normal force, prescriptions exist for ~~the tension~~ force in terms of deformation of the object — but those are

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beyond our scope { Except for Hooke's law cases that we'll come to by and by.

— So we use the 2nd or 3rd law to determine tension force $\mathbf{T}$ or $\mathbf{F}_T$

Ex 1 Particle in equilibrium

→ Means $\mathbf{a} = 0$ in inertial frames

static equilibrium means $\mathbf{a} = 0$ and $\mathbf{v} = 0$

but static equilibrium is a frame-dependent ~~state only~~ true in one inertial frame

and if true in one, true in all since $\mathbf{a}$ ~~in frame~~ is inertial frame invariant.

rope or the like

FBD

— forces exert on body treated as a point.

don't draw the forces the body exerts — that leads to horrible mess of falsely cancelling forces

Newton's 2nd law always true & and always true component by component

$$\sum_i \mathbf{F}_i = \mathbf{F}_g + \mathbf{T} = 0$$ since in equilibrium

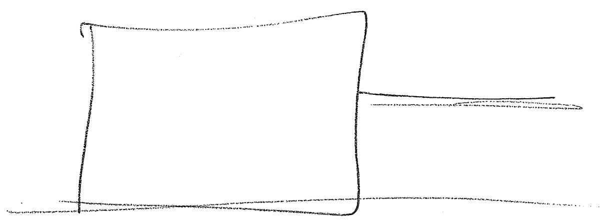
$$\sum_i F_{ix} = 0$$ but no x-direction forces at all.

$$\sum_i F_{iy} = -mg + T = 0$$

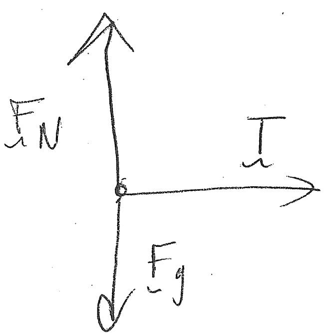
$$T = mg$$

So the 2^{nd} law and the gravity law give us the ~~tension~~ force in this case.

Ex 2 Particle under a net force



Pulling a box, horizontally



$$\mathbf{F}^{net} = \sum_i \mathbf{F}_i = m\mathbf{a}$$

Newton's law is always true and always true component by component.

$$F_y^{net} = F_N - mg = 0$$

$$F_N = mg$$

$$F_x^{net} = T = ma_x$$

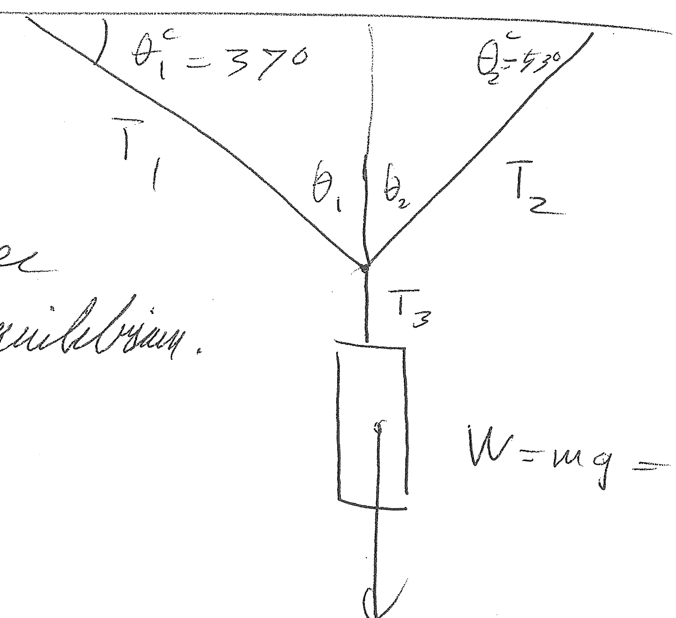
$$a_x = \frac{T}{m}$$

In this case someone has to give us T or a_x.

T can be measured using a spring

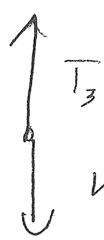
I'll introduce it ahead of the text } which relies on Hooke's law which is the one case where we have a simple prescription for tension.

Ex 5.4



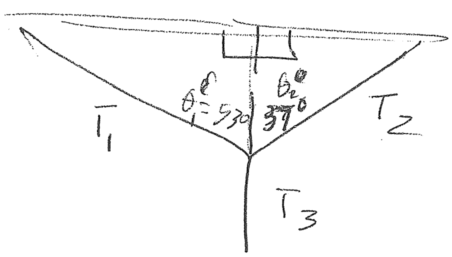
find the tension forces for static equilibrium.

FBD1



$$T_3 = mg = 122\,N$$

FBD2



Two equations, two unknowns.

$$\sum_i F_{y_i} = T_1 \cos\theta_1^c + T_2 \cos\theta_2^c - T_3 = 0$$

$$\sum_i F_{x_i} = -T_1 \sin\theta_1^c + T_2 \sin\theta_2^c = 0$$

5 - 37

— no good clever tricks I think. One just grinds out the expression

$$T_1 = T_2 \frac{\sin\theta_2^\circ}{\sin\theta_1^\circ}$$

$$T_2 \left[\frac{\sin\theta_2^\circ}{\sin\theta_1^\circ}\cos\theta_1^\circ + \cos\theta_2^\circ \right] = T_3$$

$$T_2 = \frac{T_3 \sin\theta_1^\circ}{\sin\theta_2^\circ\cos\theta_1^\circ + \cos\theta_2^\circ\sin\theta_1^\circ}$$

Using a trig identity.

$$= \frac{T_3 \sin\theta_1^\circ}{\sin(\theta_1^\circ + \theta_2^\circ)} = T_3 \sin\theta_1 \simeq 122 \cdot .8 \simeq 97$$

$$= 97\ \text{N}$$

But symmetry works too.

ANS 97.4 N

$$T_1 = \frac{T_3 \sin\theta_2^\circ}{\sin(\theta_1^\circ + \theta_2^\circ)}$$

ANS 73.4 N

$$= \frac{T_3 \cdot .6}{\sin(90)} = .6\,T_3 = 73\ \text{N}$$

$$T_2 = \frac{T_3 \sin\theta_1}{\sin(\theta_1 + \theta_2)} = T_2 = T_3 .8 = .8\,T_3 = 97\ \text{N}$$

by symmetry

ANS 97.4 N

Note ~~Like~~ I encourage students to work out general expressions symbolically before

5-38) plugging numbers.

Why? — more elegant
— gives general formula independent of particular values and so can be reused.
— shows how the output ~~values~~ quantities depend on the input quantities functionally.

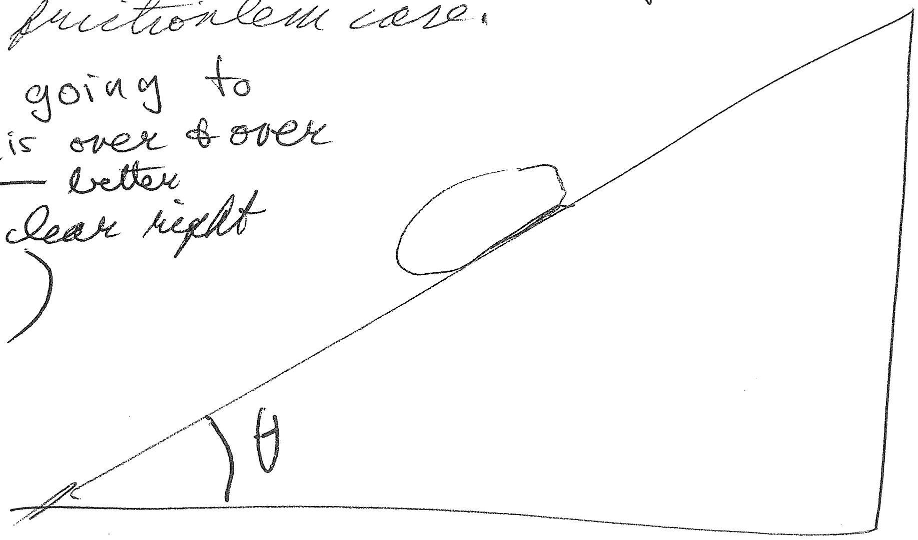
allows one ~~to~~ check your expression for logical consistency (dimensional analysis) or otherwise

But there are cases where grinding out becomes too complex and substituting values in is a necessary simplification.

Students have an awful temptation to plug numbers in as quickly as possible — as if that would get them to the answer more quickly — well it does sometimes — but the disadvantages are clear.

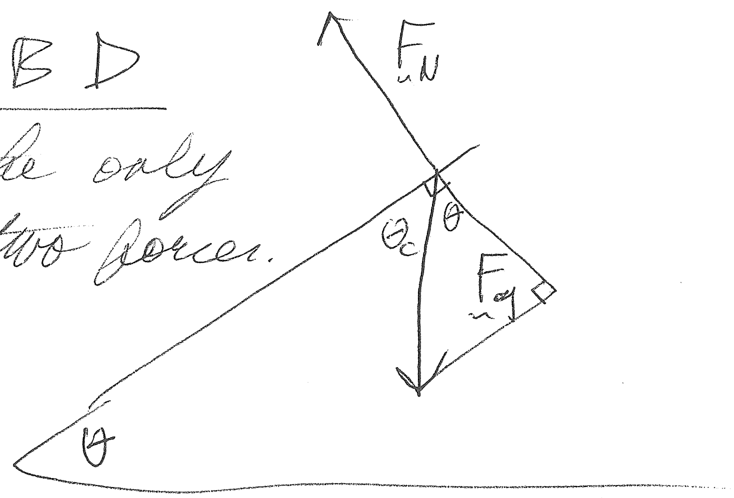
Ex 4.6 ① Object on rigid incline problem
– frictionless case.

(You are going to see this over & over again — better get it clear right off)



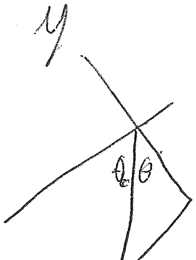
FBD

– the only two forces.



– Now we can chose the ~~axes~~ orientation of the axes for maximum convenience.

Let x-axis be parallel to plane & positive downward.



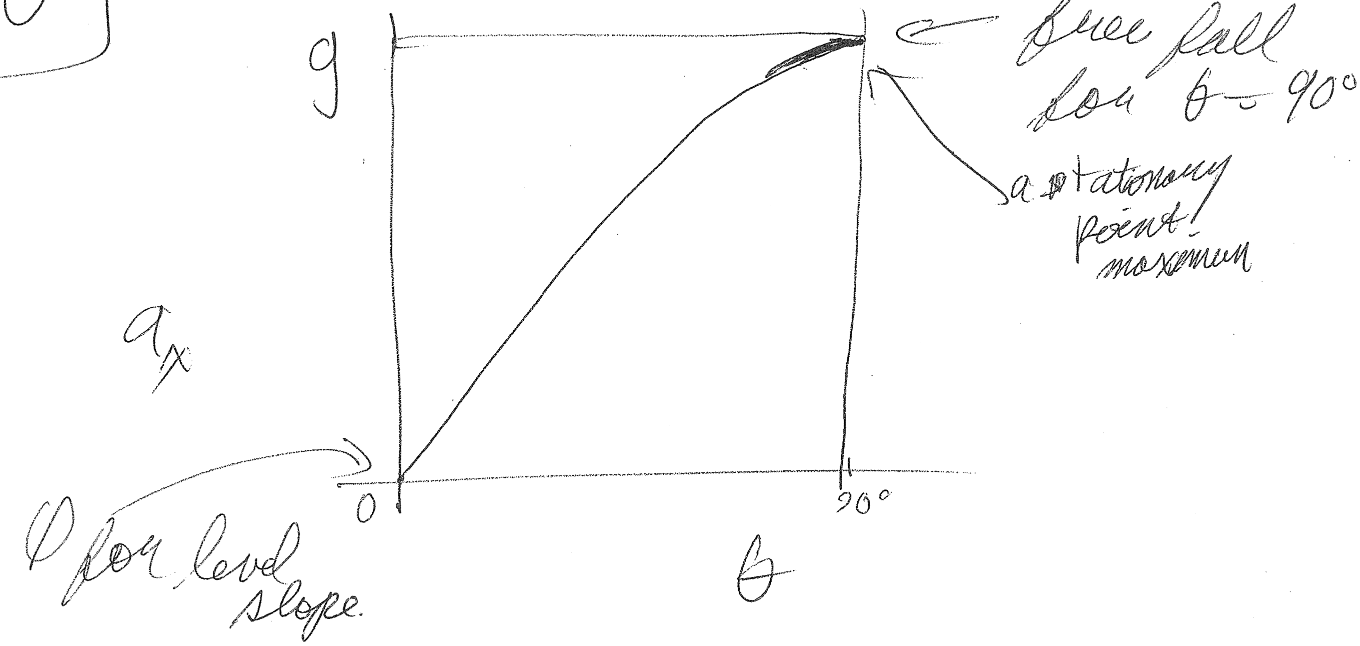
$$F_x^{net} = \sum_i F_{x_i} = mg\sin\theta = ma_x$$

$$a_x = g\sin\theta$$

→ in simple problems.

the mass cancels
– frequently that happens when gravity is involved.

5-40



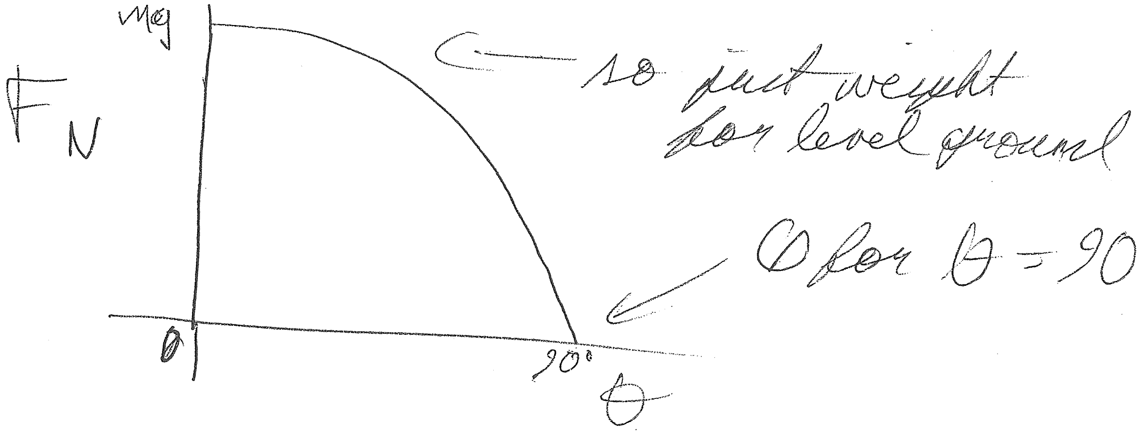
In the y-direction

$$F_{y\,net} = F_N - mg\cos\theta = ma_y = 0$$

no a_y acceleration

$$F_N = mg\cos\theta$$

we've learned the normal force from the 2nd law



Since we have ~~the~~ constant a_x we can do 1-d, constant acceleration kinematics.

Say we want the time t to slide distance Δx starting from rest

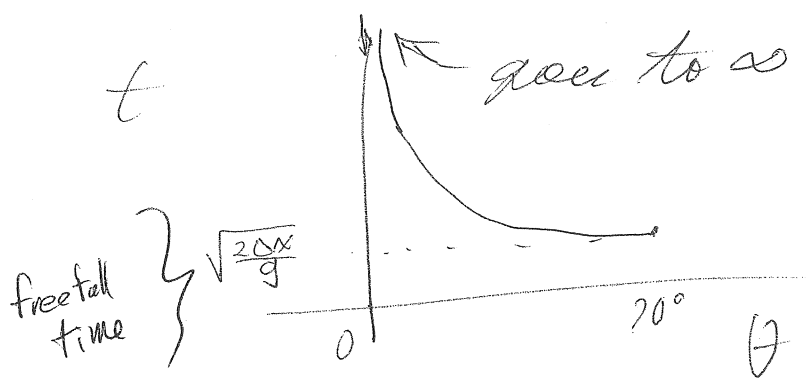
$$\Delta x = \frac{1}{2} a_x t^2 + v_{0x} t$$

$v_{0x} = 0$

$$\therefore \Delta x = \frac{1}{2} a_x t^2$$

$$t = \sqrt{\frac{2\Delta x}{a_x}}$$

$$= \sqrt{\frac{2\Delta x}{g \sin\theta}}$$



goes to ∞ for $\theta = 0$. The object is sitting at rest.

Some values. $\Delta x = 100\,m$
$g = 9.8\, m/s^2$
My standard incline angle.
$\theta = 30°$, $\sin 30° = \frac{1}{2}$

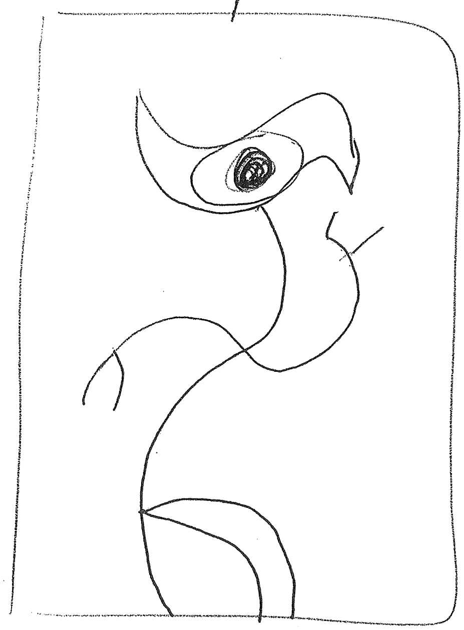
$$t \simeq \sqrt{\frac{2 \cdot 100}{10 \cdot \frac{1}{2}}} = \sqrt{40} \simeq 6.5\, s.$$

5-42

Ex 5.8 Extended

~~Life in an elevator,~~
~~Life in a non-inertial frame~~
an ~~elevator~~,

Life in an elevator



$\underset{\sim}{a}_{el} = a_{el}\hat{y}$

~~Let's first con~~

The elevator can accelerate. Then it's a non-inertial frame.

$$\underset{\sim}{F}^{net} = m\underset{\sim}{a}$$

for any object relative to non-inertial frame

But let's say the elevator is accelerating with $\underset{\sim}{a}_{el}$

Define $\underset{\sim}{a}' = \underset{\sim}{a} - \underset{\sim}{a}_{el}$

or $\underset{\sim}{a} = \underset{\sim}{a}_{el} + \underset{\sim}{a}'$

Prime Does not mean ~~differentiation~~ ~~acceleration~~ in this context also $\underset{\sim}{F}_{net} = \underset{\sim}{F}'_{net} - mg\hat{y}$

$= \underset{\sim}{F}_{other} + m\underset{\sim}{g}(-\hat{y})$

$\hat{y}$

all other forces.

the force of gravity

$\underset{\sim}{F}_{other} + m\underset{\sim}{g}(-\hat{y}) = m(\underset{\sim}{a}' + \underset{\sim}{a}_{el})$

$\underset{\sim}{F}_{other} + \underbrace{m(\underset{\sim}{g} + \underset{\sim}{a}_{el})(-\hat{y})}_{} = m\underset{\sim}{a}'$

define at

~~$\underset{\sim}{g}_{eff} = \underset{\sim}{g} - a_{el}$~~ $g_{eff} = g + a_{el}$

$\underset{\sim}{F}'_{net} = \underset{\sim}{F}_{other} + m\underset{\sim}{g}_{eff}(-\hat{y})$,

then $\underset{\sim}{F}'_{net} = m\underset{\sim}{a}'$

Just $F = ma$ even for

a NON-Inertial frame!!

But we've had to introduce the fictitious field force

5-44

$F_{\text{non-inertial}} = -m a_{el}$ to make

$F=ma$ work

in a <u>non-inertial frame</u>

This is an old trick.

– the fictitious field forces ~~generated~~ introduced to make non-inertial frames obey Newton's laws are usually called

<u>inertial forces</u>.

[There are others to be encountered later

- centrifugal force
- coriolis force

The thing ~~that~~ tries to throw you off merry-go-round. – really no force, just you trying to go in a straight line.

What does $\underset{\sim}{F}_{\text{non-inertial}} = -m\underset{\sim}{a}_{e}$ mean!

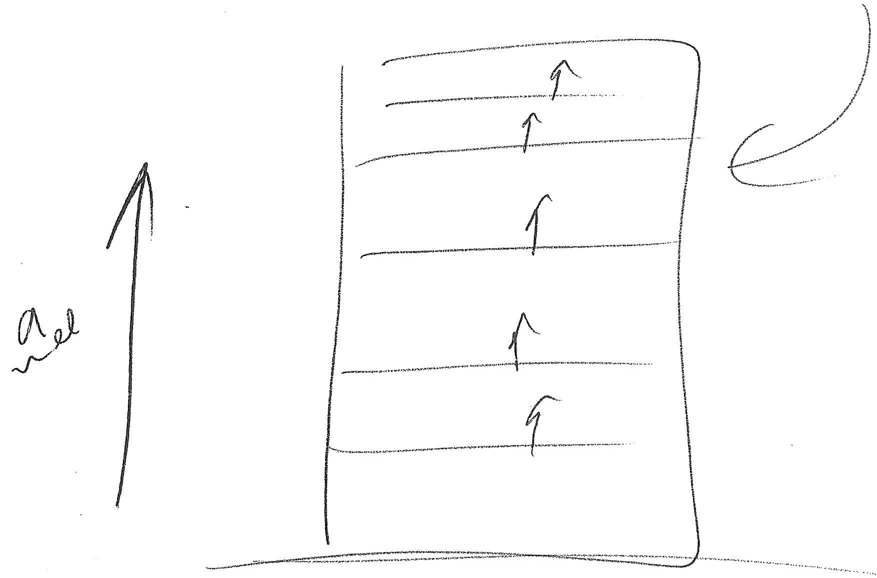
Well in a non-inertial frame with only $\underset{\sim}{F}_{\text{non-inertial}}$ acting you'd accelerate under a field force by $-\underset{\sim}{a}_{e}$ relative to the non-inertial frame

But you'd feel no stress or strain just like free-fall under gravity. → the ~~[illegible]~~ non-inertial force pulls on you atom-by-atom

really the frame is accelerating with $\underset{\sim}{a}_{e}$ and you are not accelerating relative to inertial frames.

What if you try to oppose the $-\underset{\sim}{a}_{e}$ acceleration and stay unaccelerated in the non-inertial frame — then real forces must be exerted on your body and in your body to accelerate it to $\underset{\sim}{a}_{e}$ relative to inertial frames.

normal forces on your feet in the elevator and pressure forces in your body (Treating your body not as a particle for a moment, but as a system!)



Layers by layer to accelerate all the mass above. (even layer by layer)

Those forces are just like those needed to oppose gravity.

Recall $g_{eff} = g + a_{el}$

If $a_{el} \gtrless 0$, the effective gravity is ~~increased the above~~ increased/decreased relative to gravity.

You are familiar with the sensation actually.

If an elevator accelerates upward, you feel heavier as if in a stronger gravity field

If it accelerates downward, you feel lighter as if in a lower gravity field.

If $g_{eff} = g + a_{el}$

and $a_{el} = -g$

$g_{eff} = 0$

and you are force-free – floating weightlessly in the elevator until the Big Normal force at the bottom of the shaft kicks in.

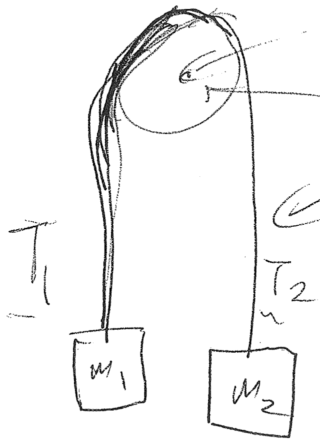
What is ~~weight~~ measured weight in an elevator

$$W = m g_{eff} = m(g + a_{el})$$

So if $g = 9.8$, $a_{el} = \pm 2$ and $mg = 40N$

$$W = mg\left(1 + \frac{a_{el}}{g}\right) \approx 40\left(1 \pm \frac{2}{10}\right) = \begin{cases} 48N \\ 32N \end{cases}$$

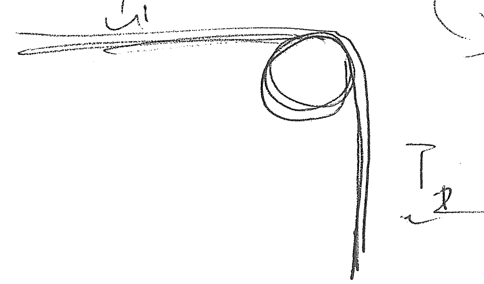
5.9 Atwood's Machine



frictionless axel
massless pulley
and rope.

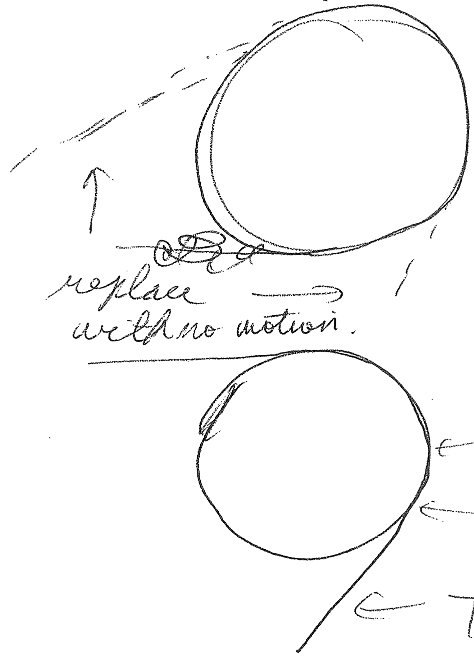
An ideal massless rope.

The tension force magnitude is the same in the rope everywhere and is transmited around the pulley unchanged.



Proof

Say in balance
— no motion or acceleration
— then symmetry dictates that $T_1 = T_2$
(the magnitudes are equal).



Consider a looped rope all around the pulley

T same everywhere by symmetry

← T

← then T here

← There as well.

Two objects to analyze

No x - forces to worry about.

$$1 \quad \sum F_{y_1} = T - m_1 g = m_1 a_1$$

y ↑ for mass 1

y ↓ for mass 2

$$2 \quad \sum F_{y_2} = m_2 g - T = m_2 a_2$$

Two equations, two unknowns. T and a

but $a_1 = a_2$ since the rope doesn't stretch.

∴ the trick to solve for a is to eliminate the unknown T.

adding is quickest way

$$m_2 g - m_1 g = (m_2 + m_1) a$$

What if $m_2 < m_1$

$a < 0$ and acceleration is the other way

$$a = \left(\frac{m_2 - m_1}{m_2 + m_1}\right) g$$

which is +ve up for 1 and +ve down for 2.

Now for solving for T is easy

$$T = m_1 a + m_1 g = m_1 (a + g)$$

$$= m_1 \left[\frac{2 m_2 g}{m_1 + m_2}\right] = \left(\frac{2 m_1 m_2}{m_1 + m_2}\right) g$$

symmetric in the 2 masses

5 - 50

If $m_2 \to \infty$,

$$\begin{cases} a = g \\ T = 2m_1 g \end{cases}$$

one $m_1 g$ to cancel gravity on mass 1
one $m_1 g$ to accelerate m_1 to g upward

Ex $m_1 = 50$, $m_2 = 60$

$$a = g\left(\frac{m_2 - m_1}{m_1 + m_2}\right)$$

$$\hat{=} 10 \frac{10}{110} = \frac{100}{110}$$

$$\simeq .9 \, m/s^2 \sim \frac{1}{10} g$$

§5.8 Friction

There are forces of resistance to motion everywhere due to the surroundings

- which is good or bad depending on your application.
- But certainly life as we know would unimaginable without them $\Rightarrow$ ~~well~~ but it would be like what we had a few

weeks ago with all the snow & ice.

— There are different kinds of resistance forces. e.g.,)

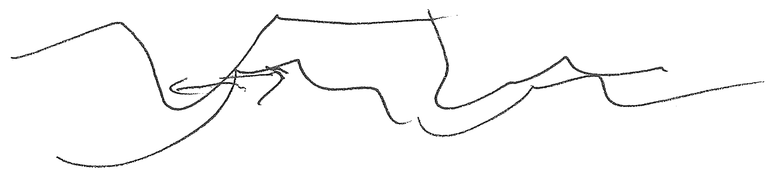
— air resistance (dealt with on Serway - 156 in Ch. 6

↳ a special case of fluid medium resistance

but

friction between macroscopically smooth surfaces is our current topic → mostly dry.

friction →



between macroscopically rough surfaces is another situation

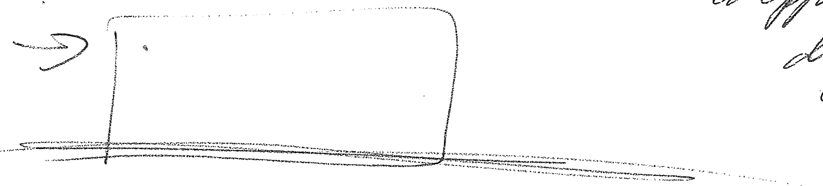
— there the normal force plays a role.

But for macroscopically smooth surfaces the friction is actually a form of chemical bonding at the microscopic level (and microscopic normal forces?)

5-52

push on a static object — friction opposes the push

sliding moving object — friction is opposite direction of motion



~~Since the friction is an attraction~~

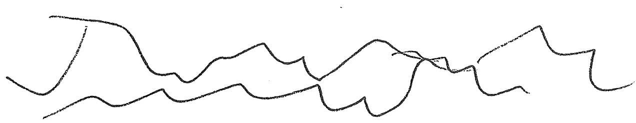
— it always opposing macroscopic motion between the surfaces

Now you might guess that

$F_f \propto$ Area of contact.

And this is ~~true~~ at the microscopic level.

but even very smooth surfaces macroscopically are rough at the micro-level.



So it is actually Microscopic contact area ~~that~~ is the key factor and one guesses.

~~Microscopic Area contact~~ $\propto$

$F_f \propto A_{microscopic} = f\, A_{macroscopic}$.

It turns out that in many cases this fraction

$$f \propto \frac{F_N}{A} = $$ Magnitude only)

The normal force pushing ~~the~~ surfaces together per unit area. (pressure actually).

$$\therefore F_f \propto A_{microscopic} \propto \frac{F_N}{A} A$$

relationship of Magnitudes not direction

$$F_f \propto F_N$$ and independent of A.

The two forces are perpendicular

This is just an approximation, but in many cases an excellent one.

— Originally discovered empirically in the 17th century by Guillaume Amontons (1663-1705)

The rule is understood ~~theoretically~~ today in terms of chemical bonding.

5-54

There are two realms

The static case $F_{f_{max}} = \text{Min}(\mu_s F_N, F_{\text{applied horizontal}})$

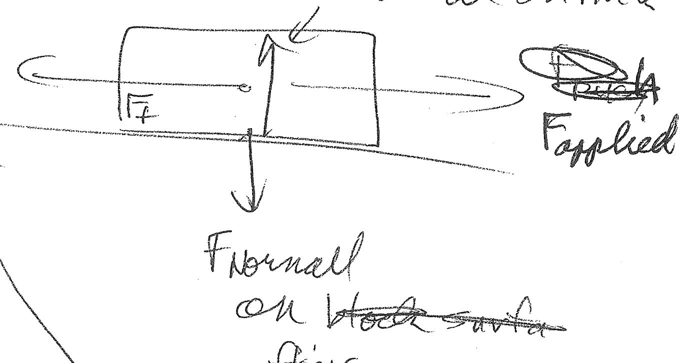
The kinetic case $F_f = \mu_k F_N$

Small Greek letter mu μ.

μ_s and μ_k are the coefficients of static and kinetic friction

Also Rolling friction See TM-13 $\mu_r \sim \frac{1}{10}$ to $\frac{1}{100}$ of μ

Just a relationships of magnitudes



μ_s & μ_k are dimensionless.

μ is the Greek m — mu sound.

The friction force is always parallel the surface and point opposite direction of applied force in static case and motion in moving case.

Actually all physicists can read Greek — we just don't know what the words mean

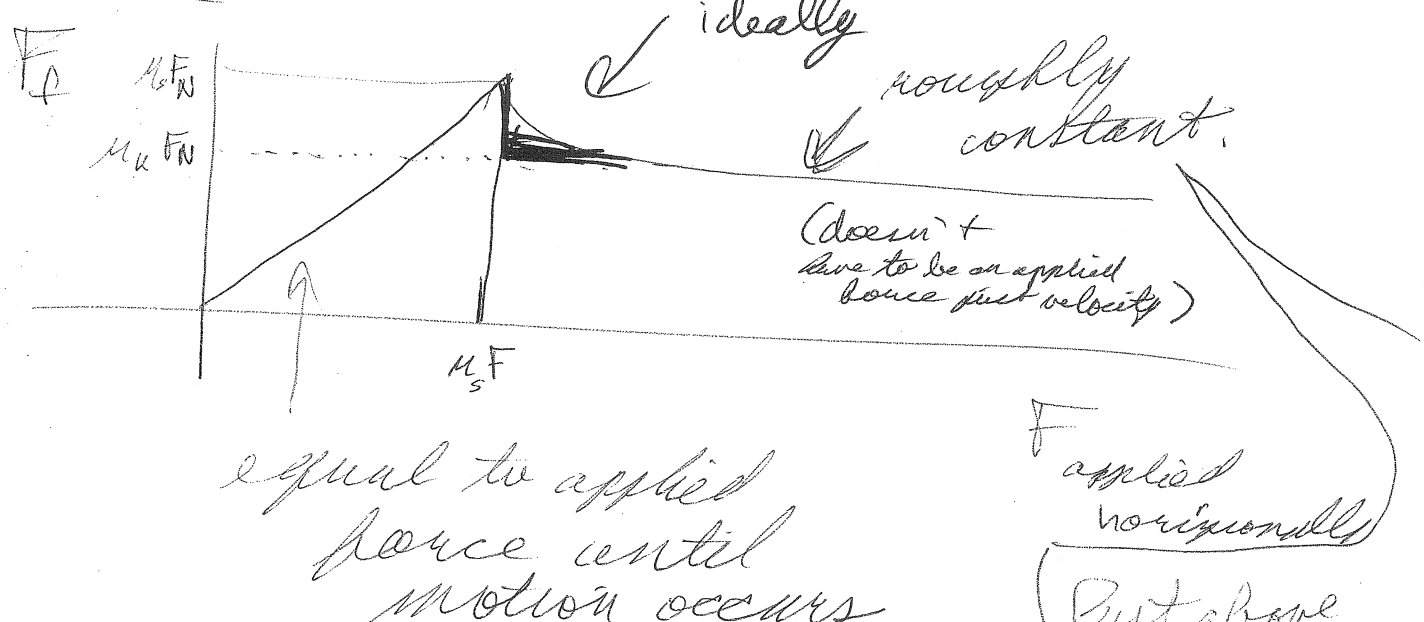
μ values typically

μ's range from .03 to 1, but they can be higher or lower

Typical plot

Fr-152

M-130



But above low speeds μ_k is speed independent.

$\mu_s > \mu_k$ usually.

— and reason for this is that in the moving or kinetic case there isn't time for a slow-forming class of bonds to form.

So the friction actually can decrease when sliding starts.

— ~~Which is a good~~

5-56

Coefficients of Friction

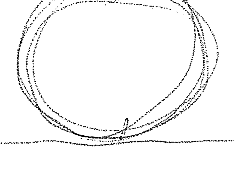
Materials	μ_s	μ_k
important case for cars — Rubber on concrete	1.0	0.8
industrially important — Steel on steel	.74	.57
Wood on wood	.25-.5	.2
Ice on ice	.1	.03

Once you start skidding your available friction goes down

These rules for friction are approximations recall.
- often are very accurate
- not always
- in problems we treat them as exact — this is an idealization.

Omit?

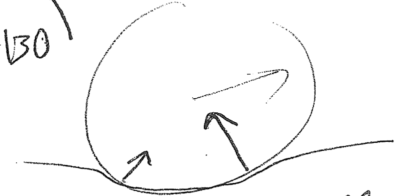
Other kind of friction rolling friction TM-130



ideally no slip and so no kinetic friction

If ball and surface perfectly rigid the ball should roll forever (conservation of ang. mom. which we come to later).

TM-130



Front deform usually stronger than rear reform. Also have to roll out of depression

but actually both deform a bit and ang. mom. (or kinetic energy) is lost in moving

$\mu_r \lesssim \frac{1}{10}$ or $\frac{1}{100}$ μ_k (TM-130)

Cold welding

— very smooth clean metal surfaces (unoxidized — so must be cut and kept in vacuum) if brought together cold weld

— essentially the bonding is so strong, the metal pieces fuse into one.

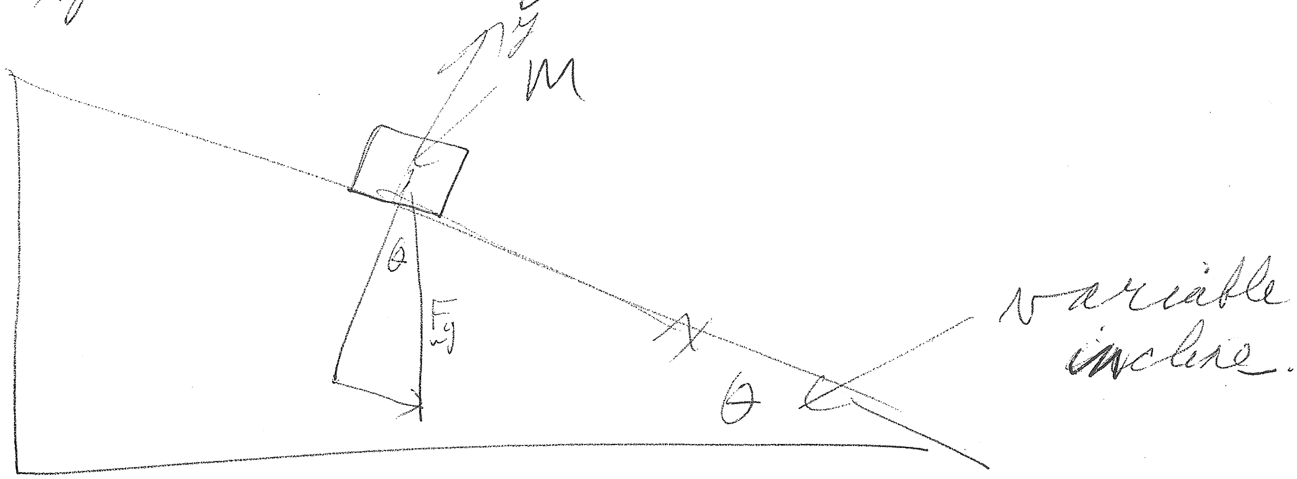
thin layer of metal oxide forms on the surfaces of most/all metals very rapidly if exposed to air even if you don't see it.

this goes beyond ordinary friction bonding

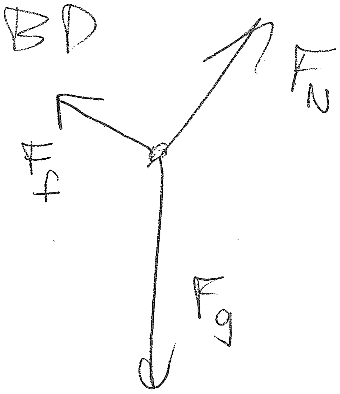
T-58

Ex 5.11

Experimentally determining μ_s & μ_k



FBD



~~In static case~~ Just writing the magnitude

$$\Sigma F_x = mg\sin\theta - F_f = ma_x$$

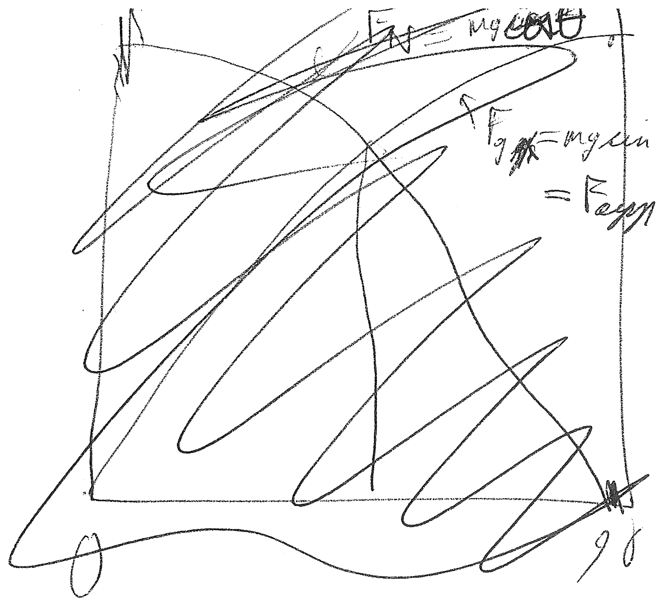
$$\Sigma F_y = F_N - mg\cos\theta = ma_y$$

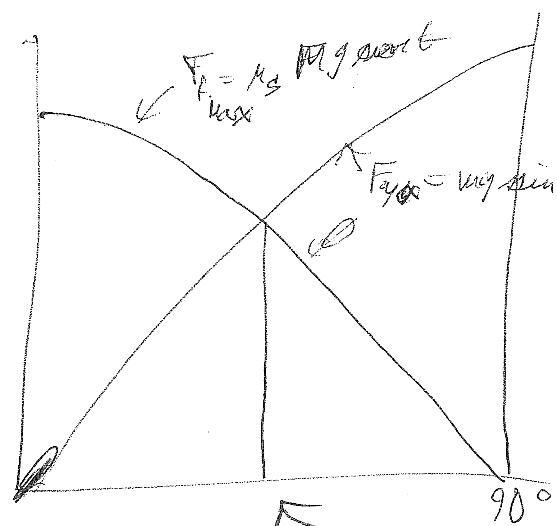
for the static case $a_x = a_y = 0$

$$F_f = \text{Min}\left[\underbrace{F_{app}}_{mg\sin\theta},\ \mu_s \underbrace{F_N}_{mg\cos\theta}\right]$$

In static case increase θ, $F_{gx} = mg\sin\theta$ increases

$F_N = mg\cos\theta$ decreases.





At cross over point sliding can just begin marginally

and $F_f = F_{f\,max} = \mu_s m g \cos\theta$

$= F_{gx} = m g \sin\theta$

∴ $\mu_s = \tan\theta_{\text{just sticking}}$ ~~just starting~~.

What of μ_k?

Well say $\theta > \theta_{\text{just sliding}}$

In this case

$$\sum F_x = mg\sin\theta - \mu_k mg\cos\theta = ma_x$$

or $g\sin\theta - \mu_k g\cos\theta = a_x$

$$\mu_k = \frac{-a_x + g\sin\theta}{\cos\theta}$$ solve for μ_k

$$= \frac{-a_x}{\cos\theta} + g\tan\theta$$

Say $a_x = 7\ \text{m/s}^2$ and $\theta = 60°$

$\mu_k \cong \frac{-7}{\frac{1}{2}} + 10(1.7)$

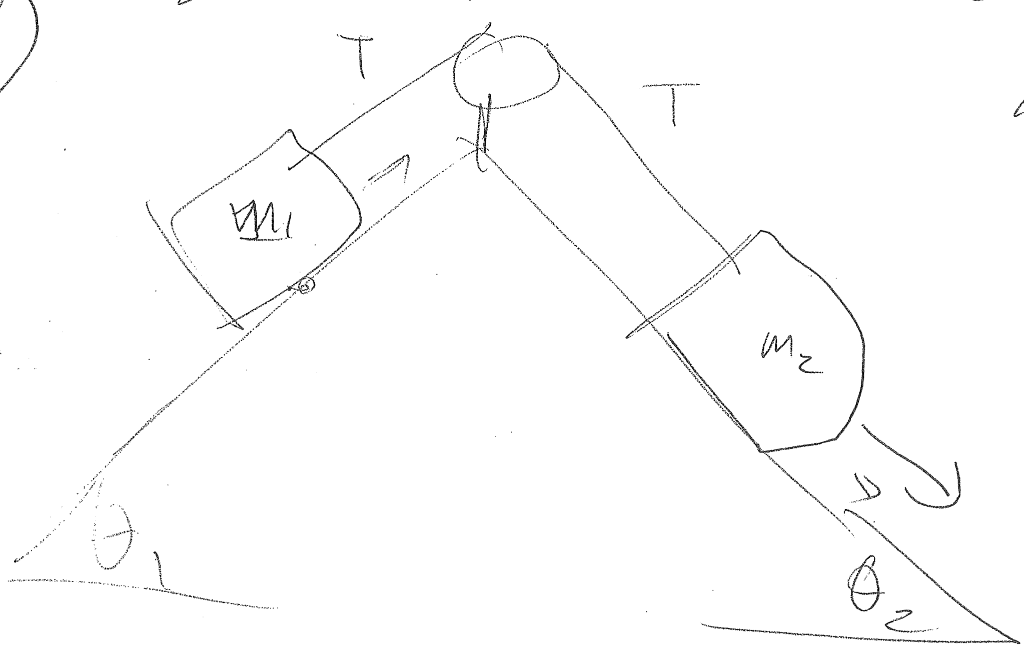
$= -14 + 17 = 3$ which is huge for a μ_k

5-60

Ex 5.13 Two objects connected by pulley with friction present

Modified since I didn't read it before I solved it

— but massless, frictionless pulley. — assuming in motion, and so a kinetic case — actually we build in that it is moving in the +x direction as we define it



$F_{N_1} = m_1 g \cos\theta_1$, $F_{N_2} = m_2 g \cos\theta_2$

$F_f = \mu_k m_1 g \cos\theta_1$ $\quad F_f = \mu_k m_2 g \cos\theta_2$

∴ 1 in x-direction

$\sum F_x = T - m_1 g \sin\theta_1 - \mu_k m_1 g \cos\theta_1 = m_1 a_1$

2 in x-direction $\sum F_x = m_2 g \sin\theta_2 - T - \mu_k m_2 g \cos\theta_2 = m_2 a_2$

No stretching and so $\} a_1 = a_2$

5-61

Easy way to get a, is to add and T cancels out.

$$(m_1 + m_2)a = m_2 g \sin\theta_2 - m_1 g \sin\theta_1 - \mu_k g\,(m_1 \cos\theta_1 + m_2 \cos\theta_2)$$

$$a = g\left[\frac{m_2(\sin\theta_2 - \mu_k \cos\theta_2) - m_1(\sin\theta_1 + \mu_k \cos\theta_1)}{m_1 + m_2}\right]$$

$\theta_1 = \theta_2 = 0$

$$g\,\frac{(-m_2 \mu_k \cancel{\cos\theta_2} - m_1 \mu_k \cancel{\cos\theta_1})}{m_1 + m_2}$$

— acceleration on level surface.

— Yes. In using kinetic friction, we assume that the masses are moving in the +x direction

— this is their ~~de~~ deceleration acceleration under friction.

5 - 62

omit — comes later.

Extra bit that

Comes up later on Serway — 171

Just want to introduce

the Spring force

or Hooke's-law force

or linear force or linear restoring force

or simple-harmonic oscillator force

all names are used.

I personally like linear force.

In 1-d

$$F = -kx$$

where x is measured from

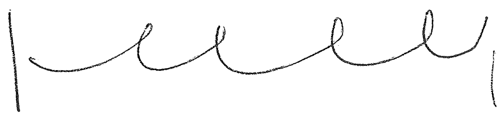
an equilibrium position $x=0$

This law applies to ideal

springs and real springs to

a degree and many systems to

a degree.



$\Delta x = 0$

$\longrightarrow$ $F < 0$ and tries to pull back

$\longleftarrow$ push in

$F > 0$ and tries to push back.

The linear force is called a restoring force since it tries to return the spring to the equilibrium position.

k is the spring constant

5-64