NEWTON'S LAWS

The foundations of modern physics begin in ancient Greece. Aristotle was among the first in western civilization to attempt to set down what he called "natural philosophy," the science that has evolved into what we call Physics. Aristotle observed that, in the world around him, objects tended to be at rest. A motionless object stayed that way unless some outside force acted on it to set it into motion. A body in motion, he noted, would eventually slow down and come to rest. He reasoned that the motionless state is the "natural" state of matter. He set this down as a basic physical principle. Another principle deduced by Aristotle is that the rate at which bodies fall (due to the earth's gravitational pull) depends on the mass of the body. Through St Thomas Aquinas, Aristotelian natural philosophy was embodied in the doctrine of the church.

It was only in the Renaissance that man's curiosity reawakened and began to question the natural laws. Galileo Galilei (1564-1642) was perhaps the first "modern" scientist. Through his application of experiment, observation and deduction Galileo founded the science of mechanics, with which we will be principally concerned in this course.

We're all familiar with Galileo's deduction that bodies fall at the same rate when they drop to the earth - independent of the mass of the [redacted] This result directly contradicted the Aristotelian doctrine. Galileo also formulated a crude version of the principle of inertia - again at odds with the principles first expounded by Aristotle and then incorporated into the [redacted] teachings of the church. These teachings, along with Galileo's other insubordinations ( ) led to his trial before the Inquisition

Galileo was sentenced to spend his last years in virtual "house arrest" in his own home. He was more fortunate than Giordano Bruno, the Renaissance philosopher who was burned at the stake for holding similar beliefs.

Upon the preliminary and incomplete structure built by Galileo, Isaac Newton, born in the year of Galileo's death, built the framework of [redacted] classical mechanics. We call it Newtonian mechanics. Newton himself said:

"If I have seen farther [than Descartes, Galileo...] it is because I have stood on the shoulders of giants."

Newton also formulated the Law of Universal Gravitation, and in order to treat mechanics properly developed the mathematical methods he called fluctions and inverse fluctions — We call them differential and integral calculus.

Newton's mechanics are based on three simple but very far reaching physical principles which we call Newton's laws

1) a body at rest will remain at rest and a body in motion will remain in uniform motion (i.e. at constant speed in a straight line) unless an outside force acts to change its motion.

This law states that the "natural state" of matter is uniform motion (the state of rest $v = 0$ is a special case), very different from Aristotle's principle — Aristotle didn't understand friction, which is the outside force which by Newton's #1 acts to alter the natural state of a body in uniform moton

This is a statement of the principle of inertia. This is quantified in Newton's 2ND law

2) The rate of change of velocity (acceleration) depends on the resultant of the forces exerted on the body divided by the mass of the body:

$$\vec{F} = m\vec{a}$$

We'll come back to this law but this gives us some definitions of important quantities

MASS - is the quantitative measure of the inertia of a body. The greater the mass, the greater the inertia, the greater resistance to change of motion

FORCE - is the "influence" which acts to change the natural state of matter - uniform motion.

NEWTON'S SECOND LAW

We have spoken of Newton's 1st Law as the Principle of Inertia, Newton's second Law quantifies this concept

"The change in motion of a body depends upon the outside influence acting on the body divided by the inertia of the body"

$$\text{Acceleration} = \frac{dv}{dt} = \text{change in motion}$$

Force = outside influence

Mass = inertia

$$\vec{a} = \frac{\vec{F}}{m}$$

or more familiarly

$$\boxed{\vec{F} = m\vec{a}}$$

In mks units

$$[a] = m\,s^{-2}$$

$$[m] = kg$$

$$[F] = kg\,m\,s^{-2} = N$$

a force of 1 N will accelerate a body of

There are two other units of force we should mention:

1) <u>cgs</u>

Since $F = ma$ the unit of force here is $g\ cm/s^2$ which is called the <u>dyne</u>

$$1\,\text{dyne} = 1\,g\,cm/s^2 = \frac{1g \cdot (10^{-3} kg/g) \cdot 1cm(10^{-2} m/cm)}{1 s^2}$$

$$= 10^{-5}\,kg\,m/s^2 = 10^{-5} N$$

For comparison a $1 kg = 1000 g$ mass weighs

$$W = 10^3 g \cdot 9.8\,m/s^2 \cdot 100\,cm/m$$

$$W = 9.8 \times 10^5 \text{ dynes.}$$

We won't use dynes much ~~they~~ but you should be aware of them.

2) British System or <u>fps</u> system

Technically the British unit of mass is the pound, but we have come to use it as <u>weight</u> making it tricky to work in this system! If we take a person's weight as 200 lb we may express his mass as $m = \frac{W}{g} = \frac{200\,lb}{}$

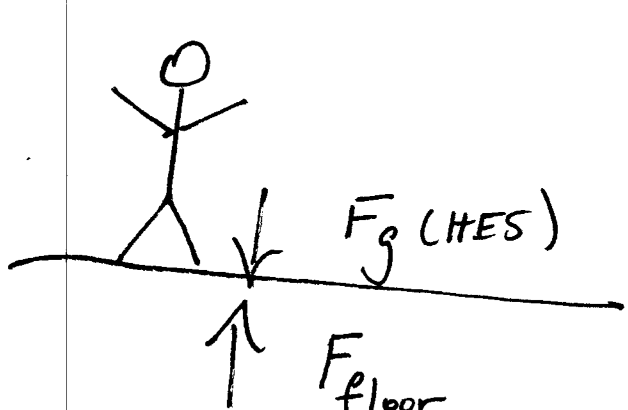
and use it in solving problems. The units in this system are meaningless. Technically there is a unit the slug for mass used in the british system such that $m = \frac{W}{g} = \frac{200 \text{ lb}}{32 \text{ ft/s}^2} = 6.25$ slugs

There is also a unit of force the poundal $= 1 \text{ lb ft/s}^2$ if one expresses the mass as lbs. Because of this dual weight (force) – mass uses of the lb unit, use of this system is confusing (not to mention tedious trying to convert lb — tons, ft to inches or yards or miles, etc) and thus little used in scientific or engineering applications.

Newton's third law concerns the mutual interactions of two bodies exerting forces upon one another

3) Whenever one body exerts a force upon another, the other body exerts a force which is equal in magnitude but in the opposite direction of the force exerted by the first body -

"For every action there is an equal and opposite reaction"



No net force thus no change of "uniform motion"

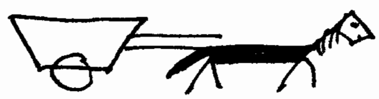
This sounds a very simple principle. but it is not, and it is important that Newton's 3rd law is understood and that action-reaction pairs be recognized and that unrelated pairs

Horse + Cart

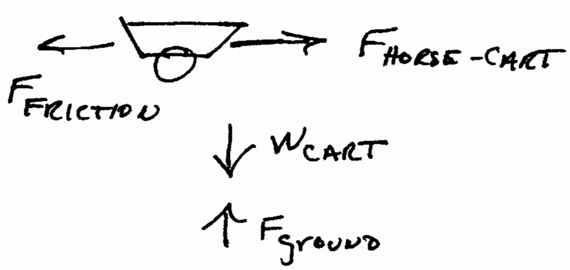
Now the horse says "I can't pull the cart —
Newton's 3rd law says:

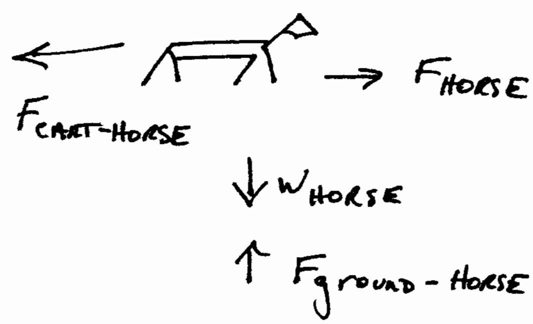
$$F_{HORSE-CART} = -F_{CART-HORSE}$$

Thus there can be no net force, no change of motion!



Free Body Diagram





Horse $F_{NET} = F_{HORSE} - F_{CART-HORSE} = M_{horse}\, a_{HORSE}$

3rd LAW

Cart $F_{NET} = F_{HORSE-CART} - F_{FRICTION} = M_{cart}\, a_{CART}$

$$a_{HORSE} = a_{CART} \equiv a$$

Add 1 + 2

$$F_{HORSE} - F_{CART-HORSE} + F_{CART-HORSE} - F_{FRICTION} = (M_{HORSE} + M_{cart})a$$

$$\text{net } \vec{F} = F_x^{HES} = 87N = m\vec{a}$$

$$a = a_x = \frac{87N}{5\,kg} = 17.4\,m\,s^{-2}$$

Now don't forget that this is the a_x that we put into our eqns for kinematics:

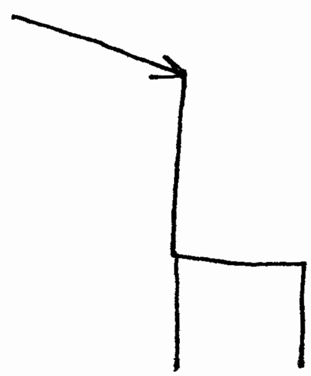
$$v_x = v_{0x} + a_x t$$

$$x = x_0 + v_{0x} t + \frac{1}{2} a_x t^2$$

Weight

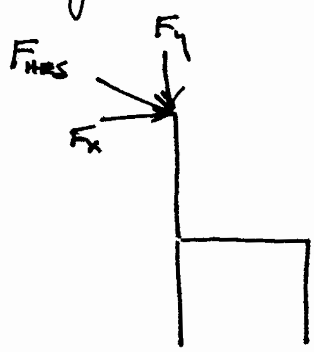
NOTE: $F_{grav} = m\,a_{grav} = m\,g$

Let's look again at forces on chair



$F_{HES} = 100N$

Free-body diagram



$\downarrow W_{CHAIR} = mg = 5kg \cdot 9.8 m s^{-2}$
$= 49N$

$\uparrow F_{floor}$

In this case

$$F_x^{HES} = F\cos 30^\circ = 87N$$

$$F_y^{HES} = F\sin 30^\circ = 50N$$

Newton's 3rd Law

$$F_{floor} = F_{chair}$$

and, since in this case $a_y = 0$

$$F_{floor} = F^{HES} + W_{chair} = 50N + 49N = 99N$$

68

in the pulley, then the tension is uniform along the entire length of the rope. The magnitude of the force it exerts on the person is the same as the magnitude of the force it exerts on the barrel.

Now let us consider in detail the unfortunate problem pictured in Fig. 3.13a. filed for workmans compensation altercation on job site

EXAMPLE 3.8 *The Guardian of London and Manchester* described the perils of a bricklayer who filed the following report:

> I was asked to bring down some excess bricks from the third floor, so I rigged up a beam and pulley, hoisted up a barrel, and tied it in place. After filling the barrel with bricks, I returned to the ground and untied the rope, intending to lower the barrel to the ground.
>
> Unfortunately, I had misjudged the weight of the bricks. As the barrel started down, it jerked me off the ground so fast and so far that I was afraid to let go. Halfway up, I met the barrel coming down and received a severe blow on the shoulder.
>
> I then continued to the top banging my head against the beam and getting my fingers jammed in the pulley. When the barrel hit the ground it burst its bottom, allowing the bricks to spill out. I was now heavier than the barrel and so I started down again at high speed.
>
> Halfway down I met the barrel coming up and received severe injuries to my shins. When I hit the ground I landed on the bricks, getting several painful cuts from the sharp edges. At this point, I must have lost my presence of mind because I let go of the line; the barrel then came down, giving me another heavy blow on the head and putting me in the hospital.
>
> I respectfully request sick leave!

Let us suppose that the mass of the barrel when loaded with bricks is 128 kg, the mass of the bricklayer is 72 kg, and the vertical distance traversed by the barrel and bricklayer is 7.2 m, as shown in Fig. 3.13a. Calculate the bricklayer's speed as he hits the overhead beam that holds the pulley.

SOLUTION Separate force diagrams are drawn for the filled barrel and for the bricklayer in Figs. 3.13b and 3.13c. We have oriented the positive y axis down for the barrel and up for the bricklayer. The downward acceleration of the barrel will then equal the upward acceleration of the bricklayer.

The y-component form of Newton's second law for the objects in the force diagrams are

$$\text{Bricklayer:}\quad T - w_{\text{bricklayer}} = m_{\text{bricklayer}}a,$$
$$\text{Barrel:}\quad w_{\text{barrel}} - T = m_{\text{barrel}}a.$$

If we add these two equations, the tension cancels from the left side leaving an equation with only the acceleration as an unknown:

$$w_{\text{barrel}} - w_{\text{bricklayer}} = (m_{\text{barrel}} + m_{\text{bricklayer}})a.$$

This equation makes sense. The barrel's weight produces a downward pull on the barrel and rope to which it is attached. But the force of the bricklayer's weight opposes that motion, so the net force in the direction of motion is the difference of these weights. This net force has to accelerate both masses, that of the barrel and that of the bricklayer. So both masses are added in the inertial term on the right.

If we now substitute
and rearrange, we can ca

a

Now we use Eq. (2.12
after traveling 7.2 m with

$v^2 = 2a(y$
$= 2(2.7$

or $v = \underline{6.3\ \text{n}}$

EXAMPLE 3.9 Two lo
sports car whose mass, incl
suitor ties a rope to the car
rope. He then lowers the ro
toward the cliff (we ignore
tion. (b) How much time d
pulled over the cliff?

SOLUTION (a) The situ
necessary to make separate
3.14b and 3.14c). We have cl
motion because the car's acc
rock along its x axis. The x-c
car is

where T is the x component
components of the weight ar
Next we write the x-con

ΣF_x

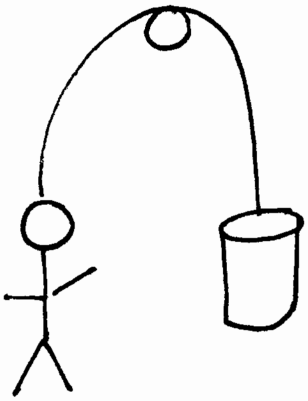
or, substituting $w_{\text{rock}} = m_{\text{rock}}$

7

If we substitute Eq. (3.10) int
that

$a_x = \left(\frac{m_{\text{rock}}}{m_{\text{car}} + m_{\text{rock}}}\right.$

(b) We now use kinematics to
cliff. We know the following in



$m_{bricklayer} = 72\,kg$

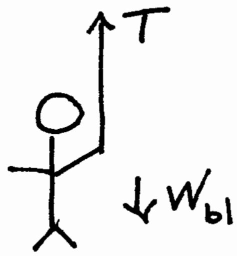
$m_{barrel} = 128\,kg$

$$W = F_{grav} = ma = mg$$

$W_{barrel} = 1254\,N \qquad W_{bl} = 706\,N$

Bricklayer

$\uparrow +y$

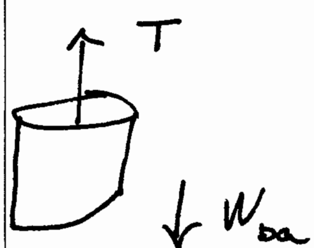


$$T - W_{bl} = m_{bl}\,a$$

(If we want consistent direction coord system must be continuous over pulley!)

Barrel

$+y \downarrow$



$$W_{barrel} - T = m_{barrel}\,a$$

(n.b. unless rope stretches $T = T \quad a = a$)

Combining $\quad W_{barrel} - W_{bricklayer} = (m_{ba} + m_{bl})\,a$

$$a = \frac{W_{barrel} - W_{bricklayer}}{m_{ba} + m_{bl}}$$

$$a = \frac{m_{ba} - m_{bl}}{m_{ba} + m_{bl}}\, g$$

$$= 0.28g = 2.74 \text{ m s}^{-2}$$