CHAPTER 3

PROJECTILES

SO FAR, WE HAVE BEEN WEIGHING AND DROPPING THINGS.

NOW LET'S SHOOT SOME!

IN ORDER TO UNTANGLE HORIZONTAL AND VERTICAL MOTIONS?

THE SIMPLEST PROJECTILE MOTION IS TO PROJECT SOMETHING SIDEWAYS: DRIVING A CAR OFF A CLIFF OR SHOOTING A BULLET HORIZONTALLY. THE KEY TO UNDERSTANDING THIS MOTION IS TO REALIZE THAT GRAVITY ACTS ONLY VERTICALLY. IT AFFECTS ONLY THE DOWNWARD PART OF THE MOTION.

NO. TO DEFEND OURSELVES FROM ALIENS DISGUISED AS TARGETS.

FORCE AND ACCELERATION ARE DOWNWARD
This fact immediately answers a famous question: If Ringo drops a bullet at the same moment as I shoot a bullet horizontally, which bullet hits the ground first? (We start at the same height.)

They reach the ground at the same time, because they fall at the same rate. The horizontal motion has no effect on the vertical motion!

Example: Suppose I fire the bullet from a shoulder height of 4 ft. Then the distance fallen is

\[ d = \frac{1}{2} gt^2, \]

\[ 4 = \frac{1}{2} (32 \text{ ft/sec}) \cdot t^2 \]

So \[ t = \sqrt{\frac{1 \text{ sec}^2}{4}} = \frac{1}{2} \text{ sec}. \]

Same downward acceleration and velocity.

If the bullet's horizontal speed is 1000 ft/sec, then it goes 500 feet in \( \frac{1}{2} \) sec.

Now here's another question: What happens if the gun is fired upward at an angle?
In the absence of gravity, the bullet would follow a straight line forever (Newton's First Law). With gravity, it falls away from that straight line!

-- which brings us to a thought-experiment called "monkey and hunter."

A hunter aims his gun directly at a monkey hanging from a tree.

The monkey cleverly releases his grip at the exact moment the hunter fires the gun. What happens?

Bwom
POOR MONKEY!! IT DOESN'T UNDERSTAND THE INDEPENDENCE OF FALLING AND FORWARD MOTION! BUT YOU DO—SO YOU CAN SEE THAT THE BULLET WILL ALWAYS HIT THE MONKEY!

IN CASE THE BULLET GOES FAST, THE BULLET AND MONKEY FALL ONLY A LITTLE WAY.

IF THE BULLET IS SLOW, THEY FALL FARTHER, BUT THEY FALL THE SAME DISTANCE FROM THE SAME STRAIGHT LINE!!
CHAPTER 4

SATELLITE MOTION AND WEIGHTLESSNESS

Now we're on the moon, where there's no air resistance. Watch as I fire bullets horizontally with greater and greater speed. Each bullet falls to the ground in the same time — the horizontal motion doesn't affect the falling rate — but the faster bullets go farther before plowing into the moon.

The gun is 4 feet off the ground. On Earth, the bullet falls in 1/2 sec., but here, where gravity is weaker, it takes 1.2 sec. (As long as the ground is level).

But as the bullets go farther, something new happens: The moon isn't flat, it's round!! The ground starts curving down under the bullet and away from it.

Eventually, as I fire faster and faster, by the time the bullet has fallen 4 ft, the ground has curved 4 ft. down and the bullet is still 4 ft. high! By the time it falls another 4 ft., so has the ground!

The bullet is now in a 4-foot-high orbit around the moon. It is falling continually, but the ground is steadily curving away beneath it.
OF COURSE, THIS WORKS ONLY WHEN THERE IS NO AIR RESISTANCE (AND NO 4-FT-HIGH OBSTACLES!) TO SLOW THE BULLET, BUT THE EXPERIMENT ILLUSTRATES THE PRINCIPLE OF SATELLITE MOTION. FROM EARTH WE LAUNCH SATELLITES ABOVE THE ATMOSPHERE WITH ROCKETS, THEN TILT THEM OVER AND GIVE THEM ENOUGH HORIZONTAL SPEED SO THAT THE EARTH CURVES AWAY FROM THEM AS THEY FALL.

SIMILARLY, OUR NATURAL SATELLITE, THE MOON, FALLS CONTINUALLY, BUT ITS FORWARD MOTION CARRIES IT ALONG SO IT REMAINS THE SAME HEIGHT ABOVE EARTH. (THE MOON'S ORBIT IS CIRCULAR, OR NEARLY SO.)
Now let's go up in the space shuttle, as we reach orbital speed and I cut off the engines, the only force on us is gravity, and we fall toward Earth.

But the same is true of the shuttle itself. It's also falling, and with the same acceleration.

So there is no relative motion between us and the ship, and we float freely inside, weightless!!
IF YOU RELEASE AN APPLE IN THE FALLING SHUTTLE, IT HANGS IN MID-AIR. GIVE IT A NUDGE AND IT TRAVELS IN A STRAIGHT LINE. IT OBEYS NEWTON'S FIRST LAW!

WHENEVER THE ONLY FORCE ON THE CRAFT IS GRAVITY, WHETHER IT'S COASTING UP, FALLING DOWN, OR IN ORBIT, OBJECTS INSIDE ARE WEIGHTLESS.

THE SCALE KEEPS FLOATING AWAY...
WE CAN DUPLICATE THE EFFECT HERE ON EARTH. JUST STEP INTO THIS ELEVATOR, AND I'LL CUT THE CABLE!!

YOU'LL ONLY BE WEIGHTLESS A LITTLE WHILE!

OH, GOOD.

THUS, ALTHOUGH GRAVITY PRODUCES ACCELERATION, NO ACCELERATION FORCES ARE FELT WITHIN THE SYSTEM.

THIS WAS ANOTHER HINT TO EINSTEIN THAT GRAVITY IS A PROPERTY OF SPACE, RATHER THAN OBJECTS.