Escaping Gravity of the Sun

Escape Velocity

In order to get to the moon, you have to escape the gravity of the earth. To get past Pluto you have to escape the gravity of the sun. The escape velocity of the earth is 11.2 km/s or 25,000 mi/h. The escape velocity of the sun at the earth's surface is 42.1 km/s or 94,000 mi/hr. The Saturn V rocket—one of the largest rockets ever built which blasted our astronauts to the moon—350 feet tall—achieved a speed of 25,000 mi/h. That was an incredible feat. But 94,000 mi/h? A rocket that big wouldn't even get off the ground!

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So how did they do it?

Despite the incredible feats of rocket scientists, they could never build a rocket large enough to go as fast as it would take to escape the gravity of the sun. So how did they do it back in the 1970's with Pioneer 10 and 11?

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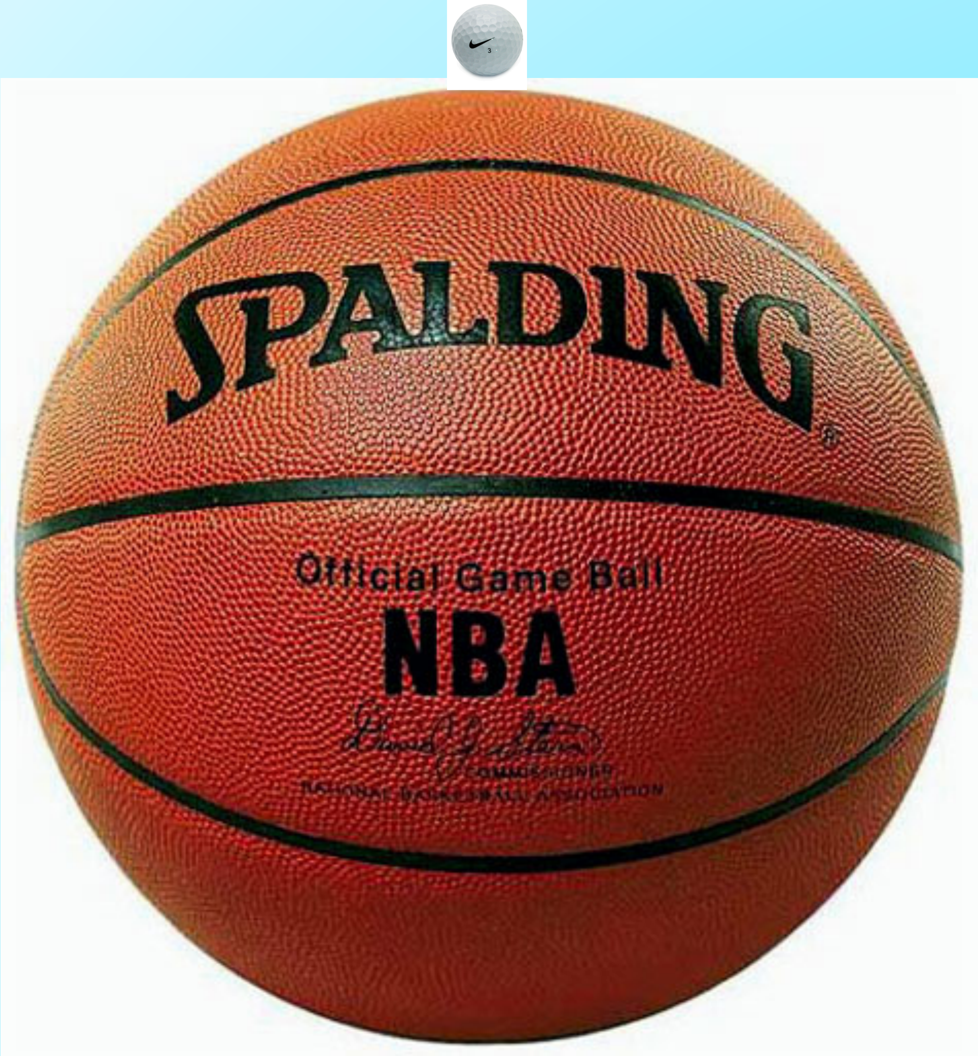
The same way baseball and tennis players do when they whallop the ball—they cause the ball to bounce—thereby increasing its speed.

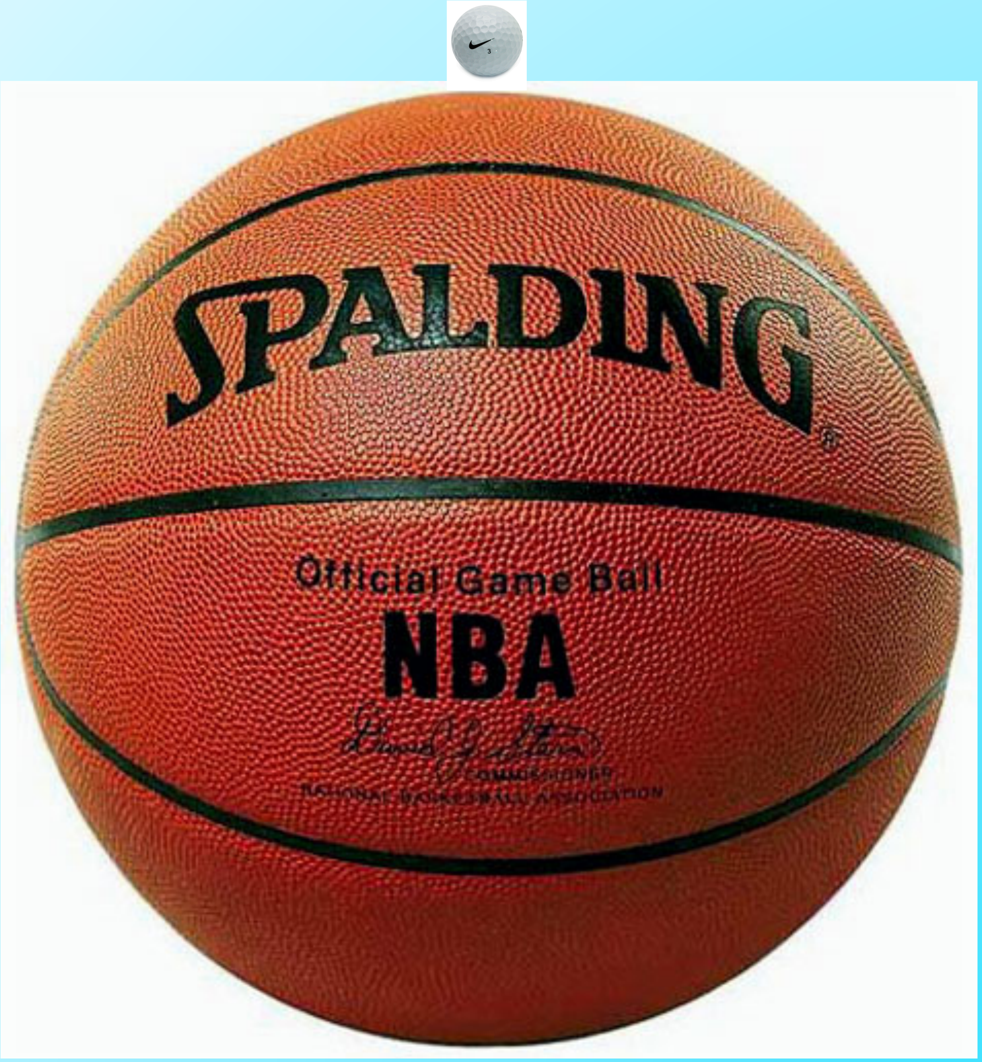
NASA scientists do it the much the same way—except they “bounce” or “bat” the spacecraft off the gravitational fields of gas giants. To see how this works, label the speeds of the balls as the fall and bounce in the following scenario. Suppose a golf ball is placed on top of a basketball and they are dropped at the same time.

Falling downwards together . . .



the relative velocity of the balls is zero.

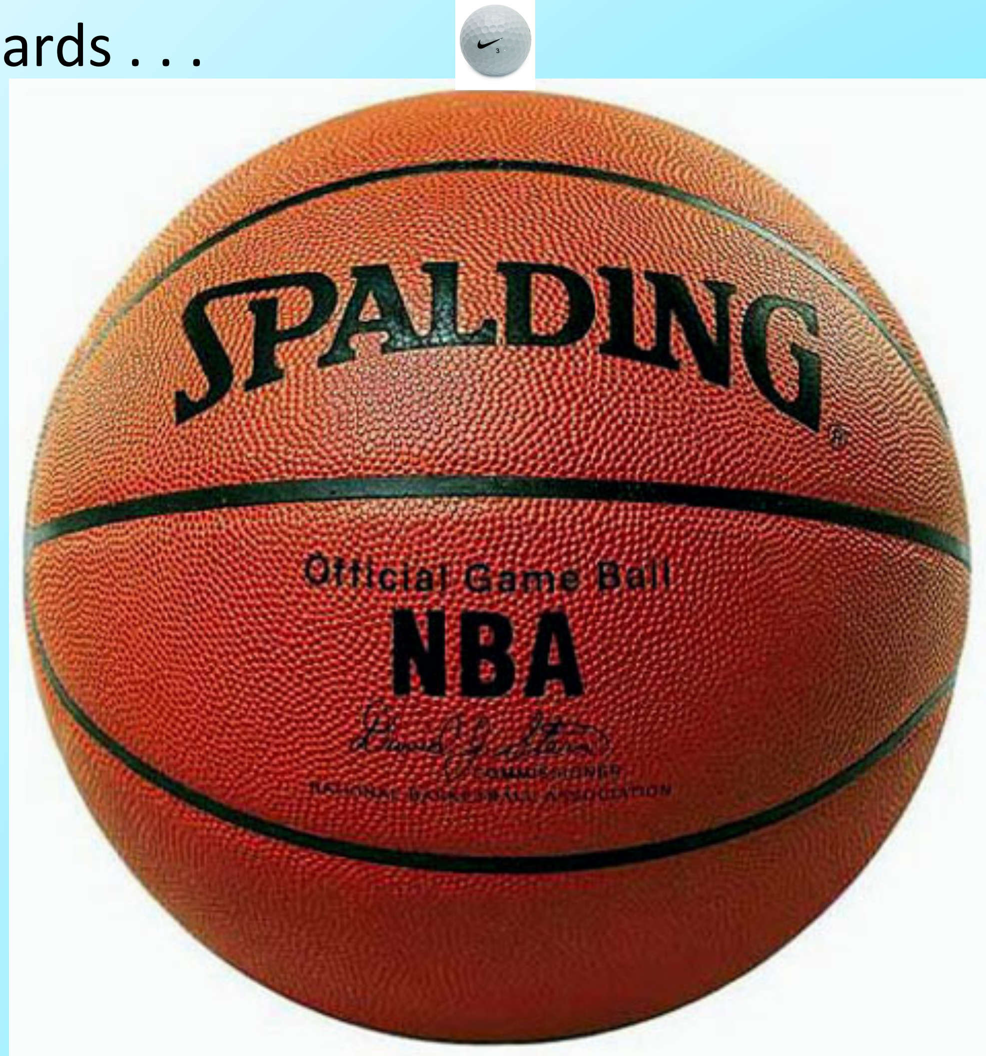
Falling downwards together . . .



Label the velocity vectors for each ball on the right side of this diagram.

the relative velocity of the balls is zero.

When the BB hits the floor, it bounces back upwards at the same speed (assuming no energy loss). However, the golf ball keeps on moving downwards . . .



Now the relative velocity of the balls is 2*v*.

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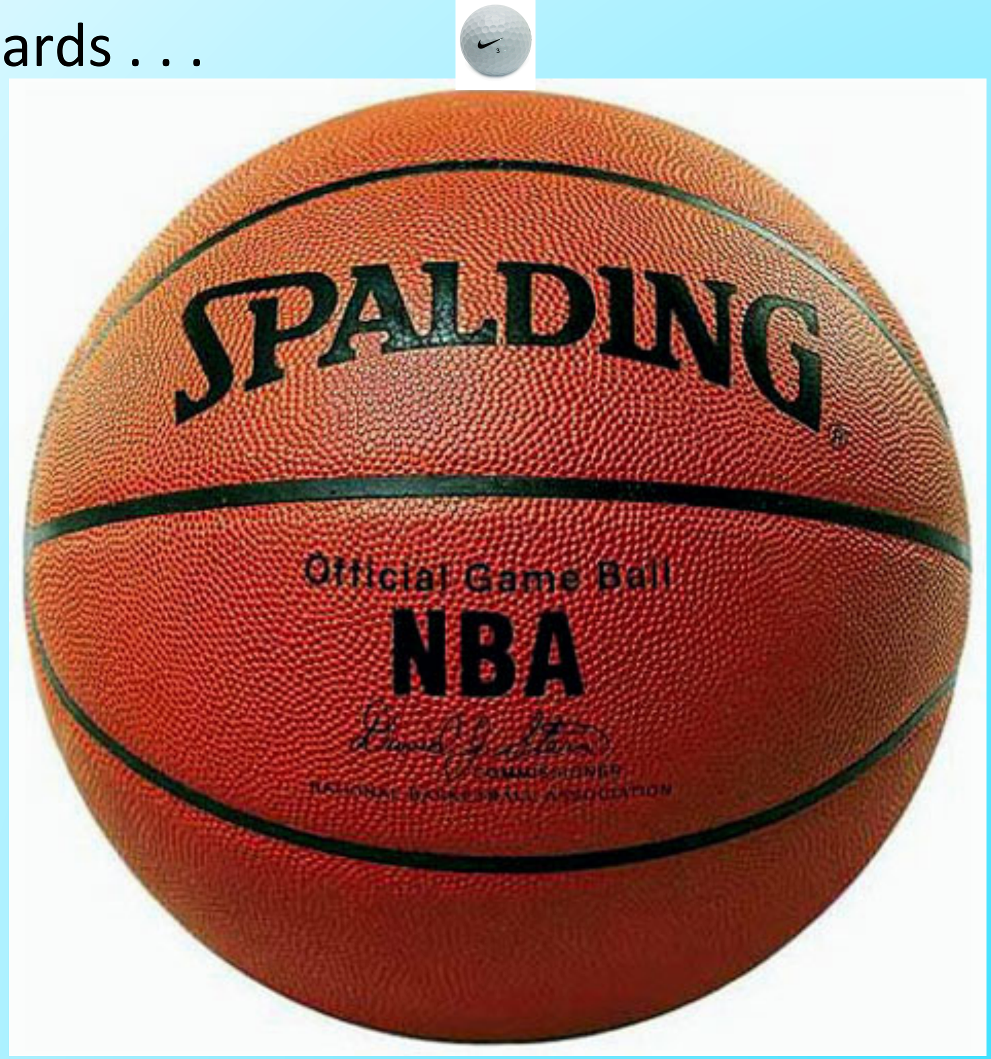
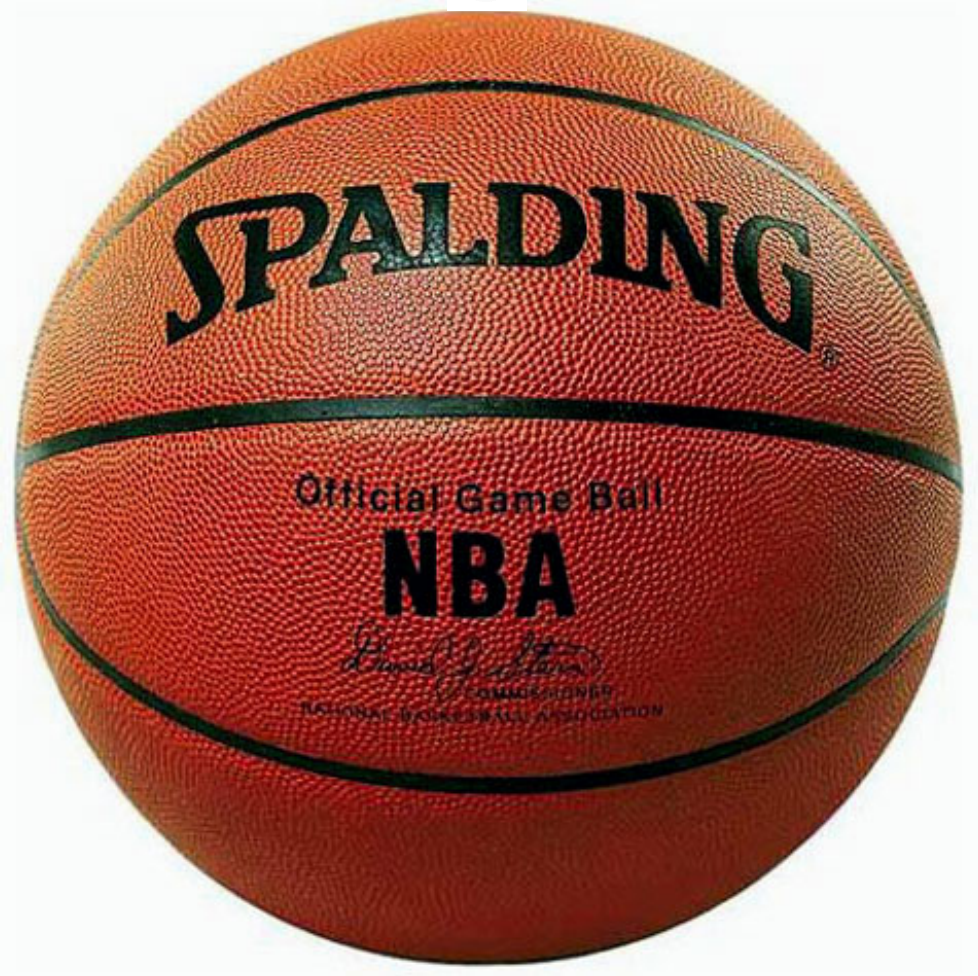


Label the velocity vectors for each ball on the right side of this diagram.

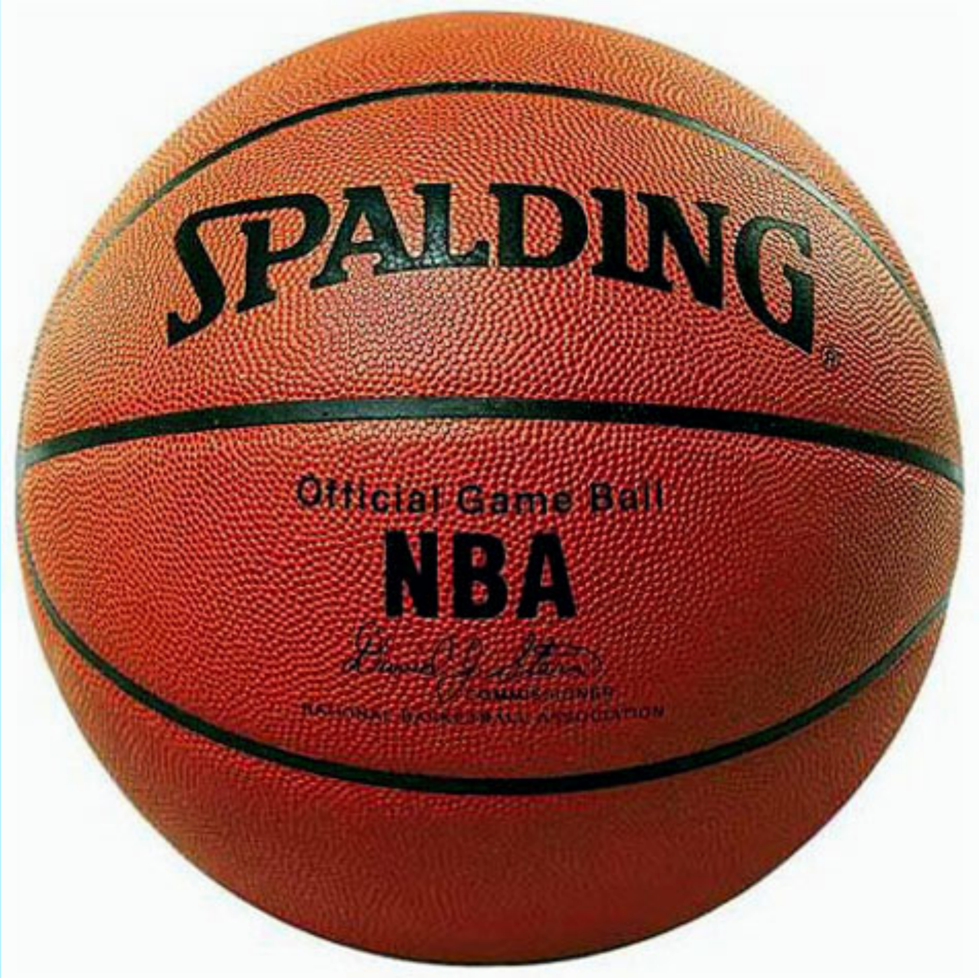
Now the relative velocity of the balls is 2*v*.

The golf ball keeps falling downwards until it encounters the upwards moving basketball. Now the golf ball bounces off the upward-moving basketball . . .



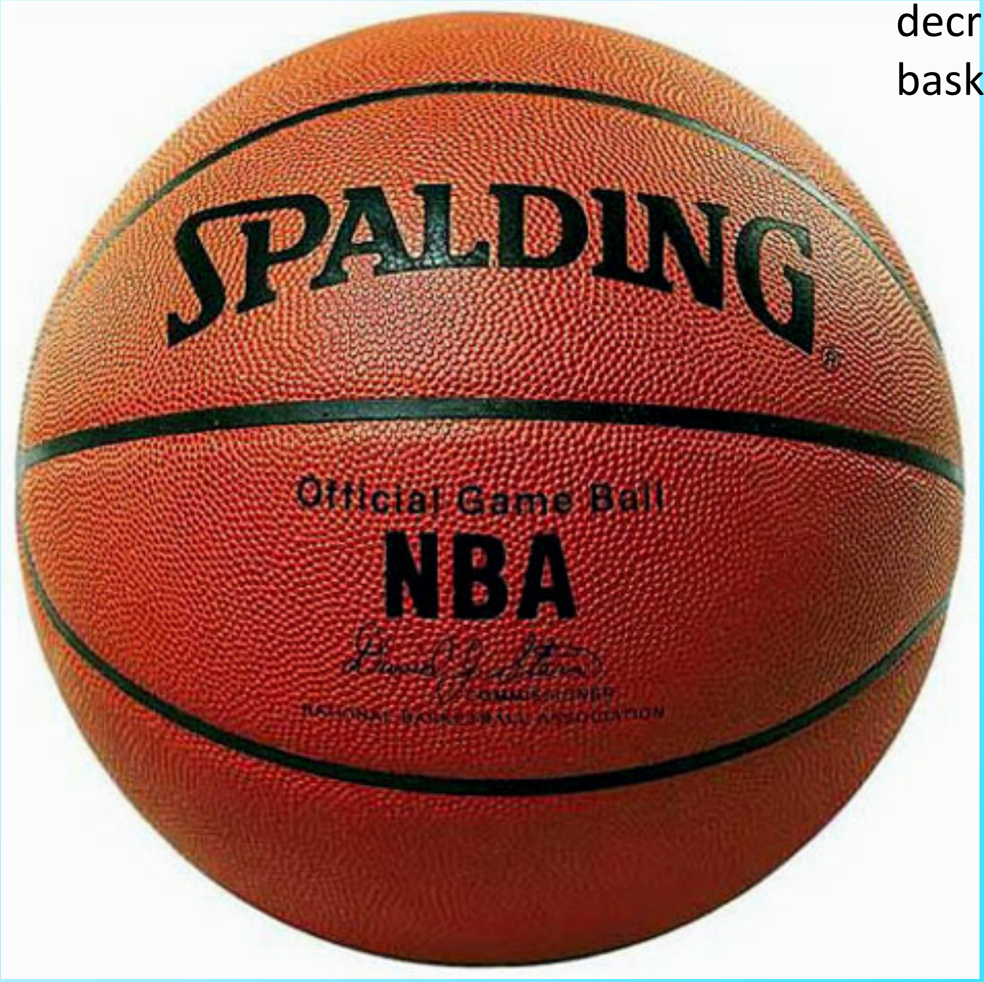
The relative velocity of approach (2v) equals the relative velocity of recession (2v).

Label the velocity vectors for each ball on the right side of this diagram.



Since the relative velocity of approach equals the velocity of recession—in this case $2v$—the golf ball ends up moving upwards $2v$ *faster* than the BB—which is $3v$!

Since the mass of the basketball is so massive compared to the golf ball, it hardly slows down—it's momentum change is minimal. However, the change in momentum of the golf ball is appreciable—it ends up going three times as fast!

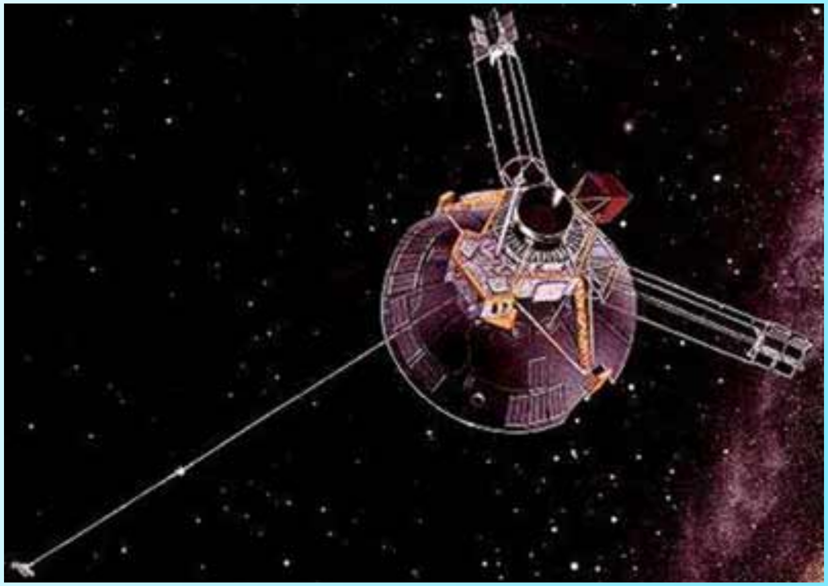


This represents a *huge* increase for the golf ball and a relatively tiny decrease for the basketball!

Pioneer 10

Since the planets coincidentally lined up during the 1970's, it made sense to attempt such a feat. Pioneer 10 was launch launched March 2, 1972. It was accelerated for 17 minutes and achieved a speed of over 32,114 mph passing the moon in just 11 hours!

The gain in speed and momentum of the golf ball comes from bouncing off the basketball. Rocket scientists did much the same thing with the Pioneer 10 and 11 except they bounced off the gravitational field of Jupiter.



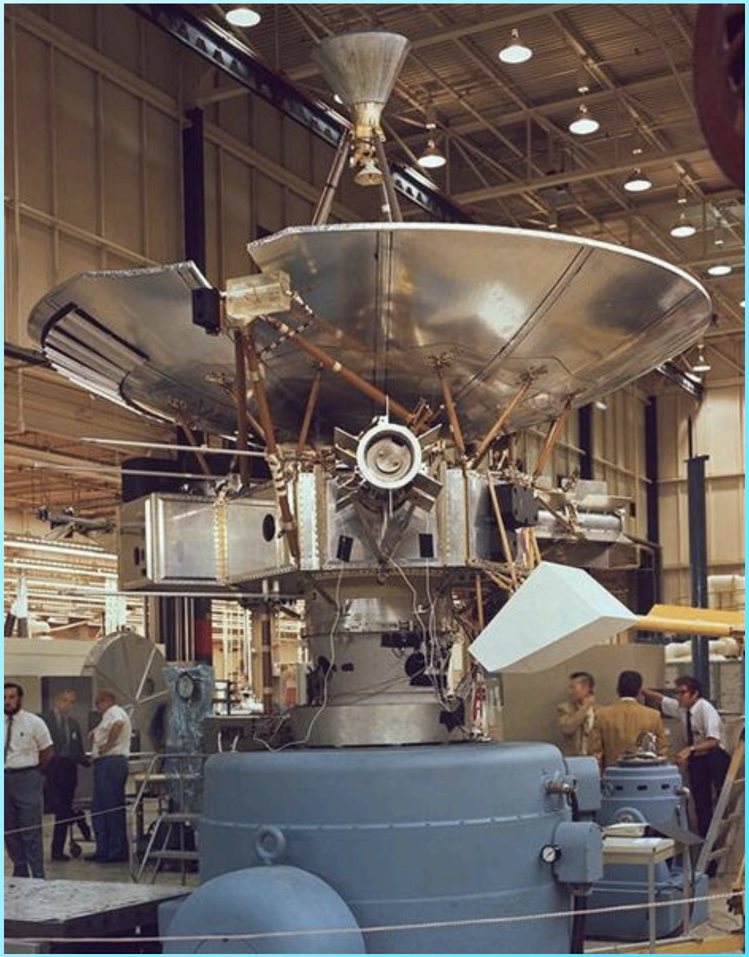
This enabled them to increase the speed of the spacecraft sufficiently large so that it escaped the gravitational pull of the sun. This effect is called the gravitational sling-shot or gravitational assist.

Pioneer 10

Since the planets coincidentally lined up during the 1970's, it made sense to attempt such a feat. Pioneer 10 was launched aboard an Atlas-Centaur rocket March 2, 1972. It was accelerated for 17 minutes and achieved a speed of over 32,400 mph passing the moon in just 11 hours!

Now that's a *hit*!

Pioneer 10

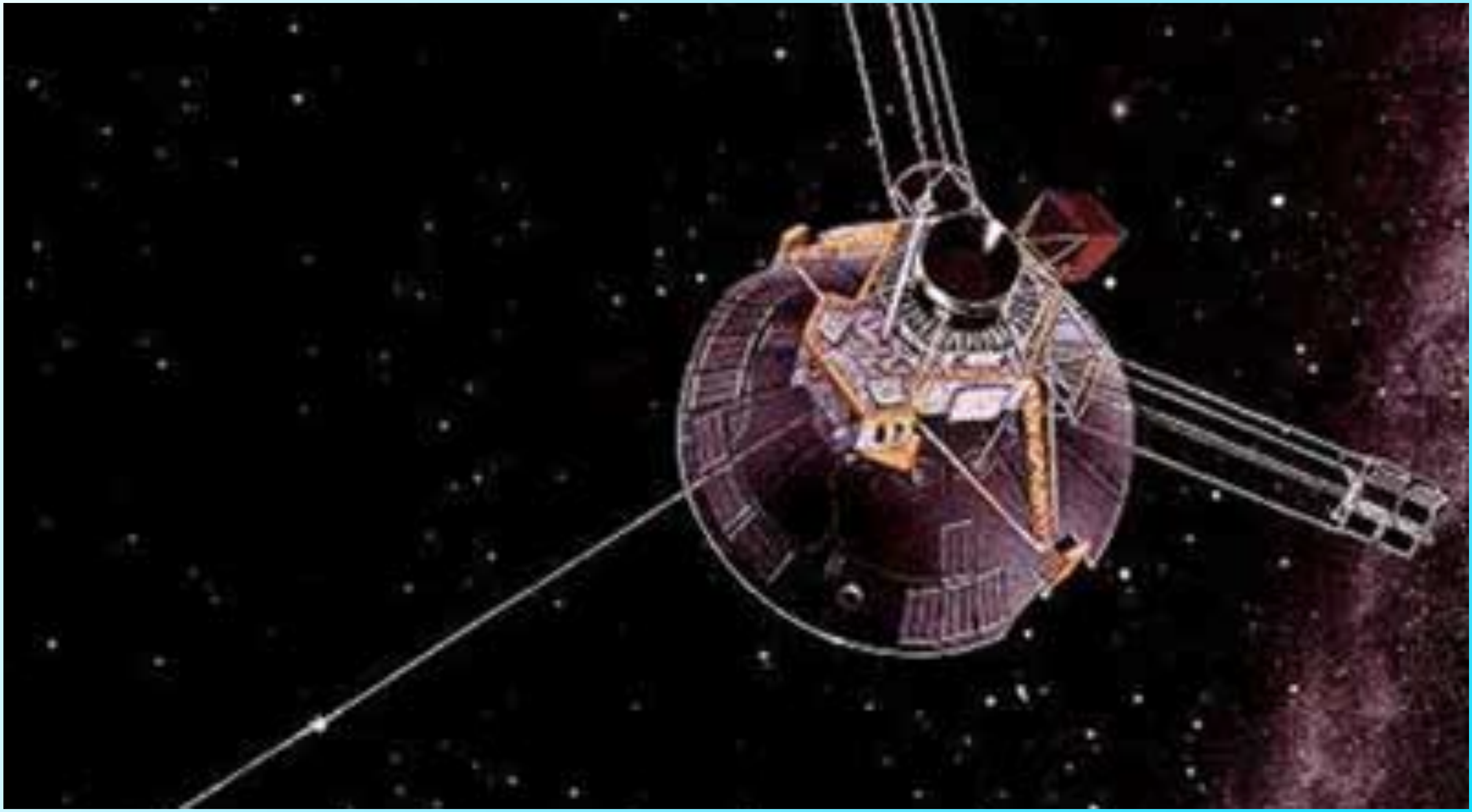


The mission was operated at NASA Ames Research Center. The principal investigator was James Van Allen—the discoverer of the Van Allen radiation belts. The Pioneer 10 was the first spacecraft to ever venture through them and the asteroid belt.

Pioneer 10

Pioneer 10 was built built by TRW in Redondo Beach, CA.

Pioneer 10



The first man-made spacecraft to leave the solar system, it crossed the path of Pluto's orbit in about 11 years after it was launched in 1983. It continued to work far beyond its expected lifetime. Last contact was in 2003—almost 30 years later.

How Escape Speeds are Calculated

The basic concept is based on the conservation of energy. The KE of the satellite at launch equals the PE at the escape point.

$$KE_{lost} = PE_{gained}$$

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

How Escape Speeds are Calculated

Solving for *r*:

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

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

How Escape Speeds are Calculated

Recall the the minimum speed for circular orbits is:

$$v_{orbital} = \sqrt{\frac{GM}{r}}$$

How Escape Speeds are Calculated

Recall the the minimum speed for circular orbits is:

Therefore: $v_{escape} = \sqrt{\frac{2GM}{r}}$

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

$$v_{escape} = \sqrt{2}v_{orbital}$$

Escape Compared to Orbital Speed

$$v_{escape} = \sqrt{2}v_{orbital}$$