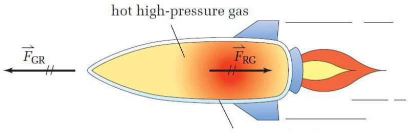
SPH4U UNIVERSITY PHYSICS

ENERGY & MOMENTUM

☞ Energy & Momentum in Space (P.~)

Propulsion in Space

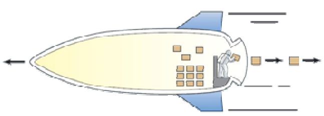
Newton's third law of motion states that if you exert a backward force on an object, that object will exert a forward force on you. This concept is the basis for all motion and manoeuvring of astronauts and rockets in space.



$\vec{F}_{GR}$ = force exerted by the gas on the rocket (thrust) [forward]
$\vec{F}_{RG}$ = force exerted by the rocket on the gas [backward]
$\vec{F}_{GR} = -\vec{F}_{RG}$

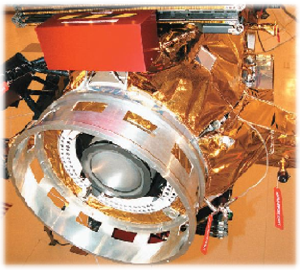
Propulsion in Space

In fact, a spacecraft could be propelled by having an astronaut stand at the rear of the spacecraft and throw objects backward. This process is an example of recoil.



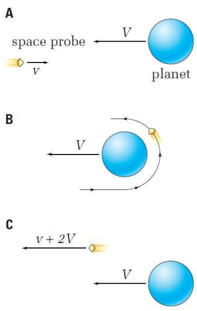
Propulsion in Space

The process of burning fuel is not the only way to generate thrust. One extremely efficient method involves an ion engine, such as the one shown. In an engine such as this, gas atoms are ionized and the resulting positive ions are driven backward by electrostatic repulsion. The thrust is quite low, but it can act steadily month after month, year after year, gradually increasing the velocity of the spacecraft.



Gravitational Assist

Sometimes, free energy seems to be gained for a spacecraft through a manoeuvre known as ***gravitational assist*** *or a* ***gravitational slingshot****. The celestial slingshot process involves directing a spacecraft to swing around a planet, while keeping far from the atmosphere of the planet.*



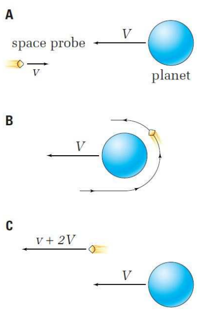
Gravitational Assist

NOTE!

The interaction represents an extremely elastic collision, even though the objects do not actually meet. As a result, if the spacecraft arcs around the planet and returns parallel to its initial path, it will gain a speed of 2V, which is twice the orbital speed of the planet.

PRACTICE

1. Prove the spacecraft gains a speed of 2V.



Gravitational Assist

Use motion to the left as positive.
A = space probe, B = planet (so $m_B >> m_A$)

$v_{Bi} = V$ {- V} make $v_{Bi} = 0$ by - V
$v_{Ai} = -v$ {- V} do the same to v_{Ai} …

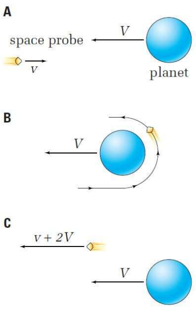
$$v_{Af} = \left(\frac{m_A - m_B}{m_A + m_B}\right) v_{Ai} \qquad v_{Bf} = \left(\frac{2m_A}{m_A + m_B}\right) v_{Ai}$$

$$v_{Af} = (-1)(-v - V) \qquad v_{Bf} = 0(-v - V)$$

$$v_{Af} = v + V \ \{+ V\} \qquad v_{Bf} = 0 \ \{+ V\}$$

now do the opposite {+V} to get the real v_f

$v_{Af} = v + 2V$ $\qquad$ $v_{Bf} = V$



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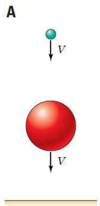
Superball Boost

A similar effect can be seen on Earth. For example, if a tiny superball is held just above a more massive ball and they are dropped together, the superball will rebound at high speed from the collision. Consider the following situation:



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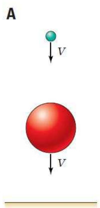
Superball Boost

(A) Both balls are falling at the same speed.



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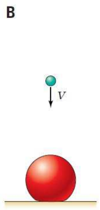
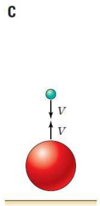
Superball Boost

(B) The large ball hits the ground and rebounds.



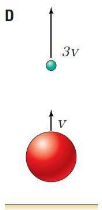
Superball Boost

(C) If the collision is elastic, it rebounds with the same speed it had before hitting the ground.



Superball Boost

(D) The two balls are now approaching each other at a speed of 2v. If their collision is elastic, since the large ball is only slightly slowed down in the collision, the small ball will rebound with a speed of 3v.



PRACTICE

2. Prove that the rebound speed of the superball is 3v.

Superball Boost

Use motion upward as positive.

A = superball, B = large ball (so $m_B >> m_A$)

$v_{Bi} = v$ {- v} make $v_{Bi} = 0$ by - v

$v_{Ai} = -v$ {- v} do the same to v_{Ai} …

$$v_{Af} = \left(\frac{m_A - m_B}{m_A + m_B}\right) v_{Ai} \qquad v_{Bf} = \left(\frac{2m_A}{m_A + m_B}\right) v_{Ai}$$

$$v_{Af} = (-1)(-v-v) \qquad v_{Bf} = 0(-v-v)$$

$$v_{Af} = 2v \quad \{+ v\} \qquad v_{Bf} = 0 \quad \{+ v\}$$

now do the opposite {+v} to get the real v_f

$v_{Af} = 3v$ $v_{Bf} = v$