Astronomy 330

This class (Lecture 23):
Interstellar Travel
Janet Pauketat

Next Class:
Interstellar Travel

HW11 is due next Thursday. Fun one, but still not multiple choice.

Music: *Rocket Man*– Elton John

Online ICES

- ICES forms are available online.
- I appreciate you filling them out!
- Please make sure to leave written comments. I find these comments the most useful, and typically that's where I make the most changes to the course.

Presentations

- **Janet Pauketat:** Aliens in the News

Outline

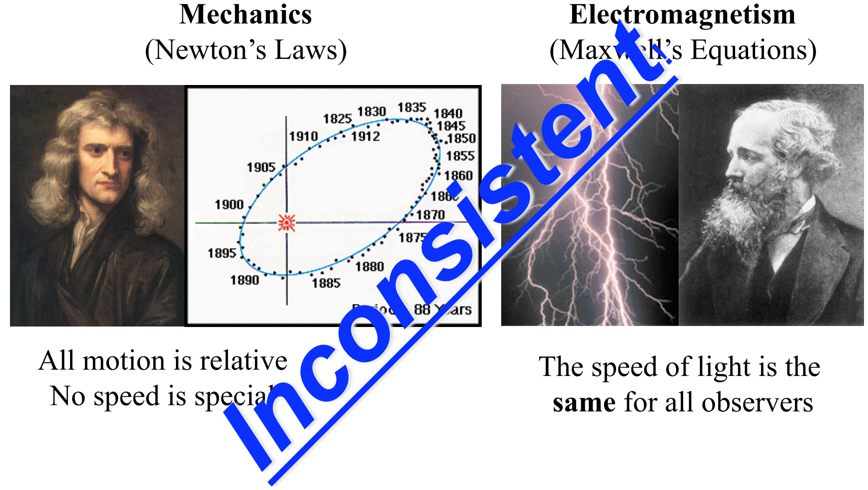
- If we have to go find ET, then how to get out there?
- Interstellar travel problems

How Fast is Light?

- The speed of light is $c = 3\times10^8$ m/s (186,000 miles per second)!
- How fast is that?
  - Around the Earth over 7 times in a second
  - From Earth to the Moon in under 2 seconds (it took the Apollo astronauts 3 days)
  - From the Sun to the Earth in a little over 8 minutes
  - From the Sun to Pluto in about 5½ hours
  - From the nearest star to Earth, about 4 years

Two Threads of Thought in Physics up to 1900

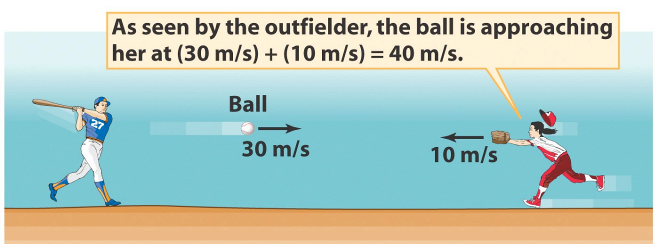
Mechanics (Newton's Laws)	**Electromagnetism** (Maxwell's Equations)



All motion is relative
No speed is special

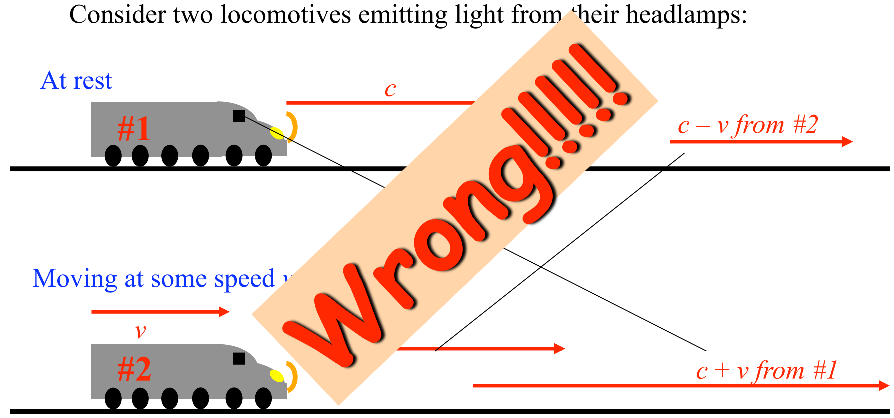
The speed of light is the **same** for all observers

Why Newton and Maxwell Can't Both Be Right

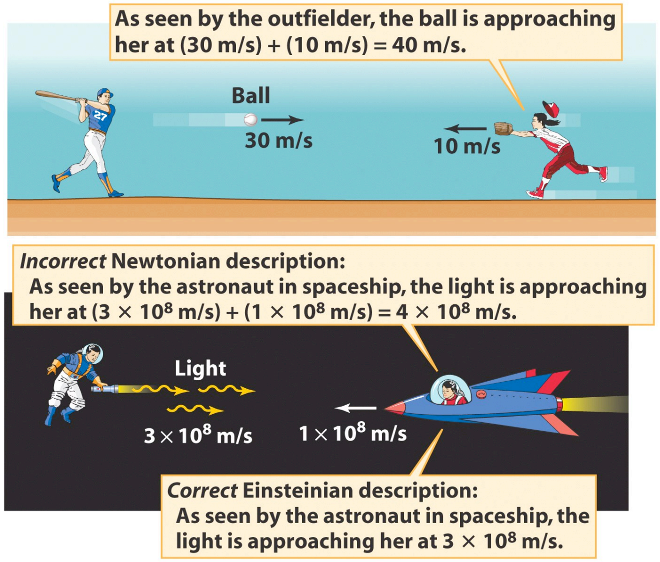


Why Newton and Maxwell Can't Both Be Right

Consider two locomotives emitting light from their headlamps:



Why Newton and Maxwell Can't Both Be Right



Why Newton and Maxwell Can't Both Be Right

So the speed of light can't be the same for everyone if Newton – and our intuition – are right. But Maxwell says it is constant!

Something must happen. And what must happen for Newton and Maxwell to be both right, is that there is a modification of time and distance. Remember

$$speed = \frac{dist}{time}$$

Distance and time become relative to the observer.

Question

You are at the back of a jet traveling at 400 mph. You shine a laser toward your friend in first class. What speed does your friend measure for the laser light?

a) c+400 mph
b) c-400 mph
c) c
d) c/400 mph
e) c/(c^2-400^2) mph

Where c is the speed of light.

Approaching the "c"

- Time dilation – Moving clocks run slow.
- Length contraction – Moving objects contract along direction of motion.
- Mass increase – moving clocks get more massive

http://www.richard-seaman.com/Travel/Japan/Hiroshima/AtomicBombMuseum/IndividualArtifacts/

Approaching the “c”: Impact

- The clocks on a ship accelerating to “c” would stop completely compared to someone at rest.
- The ship would appear to be infinitely thin in length along its direction of motion for someone at rest.
- The mass of an object as it approaches “c” becomes infinite for someone at rest.
  - So does its kinetic energy– requires more power.

http://www.richard-seaman.com/Travel/Japan/Hiroshima/AtomicBombMuseum/IndividualArtifacts/

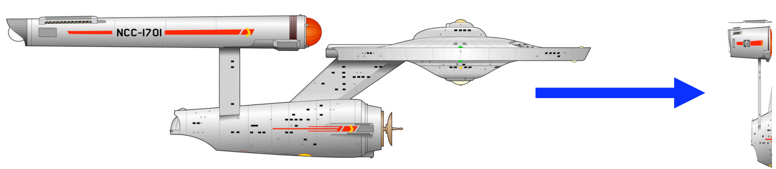
Gamma

The factor by which all of these changes occur is called “gamma”

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

Counterintuitive Result #1

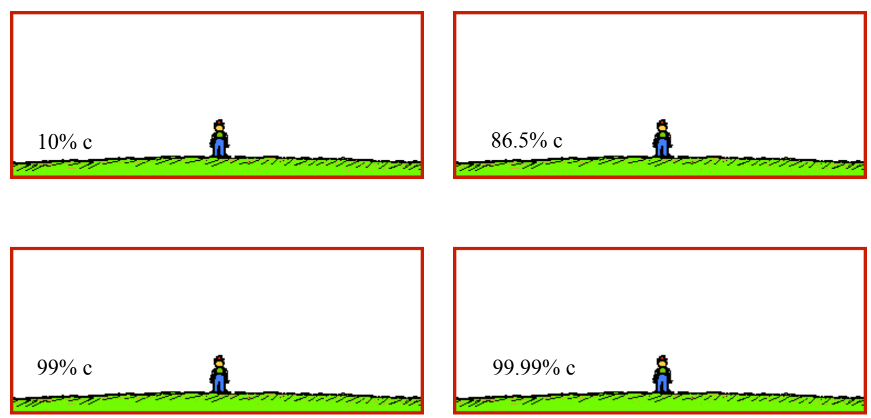
Moving objects appear shorter in the direction of relative motion



Fraction of the speed of light	% of original length
0.00	100%
0.001	99.99995%
0.01	99.995%
0.1	99.5%
0.5	86.6%
0.9	43.6%
0.99	14.1%

Counterintuitive Result #1

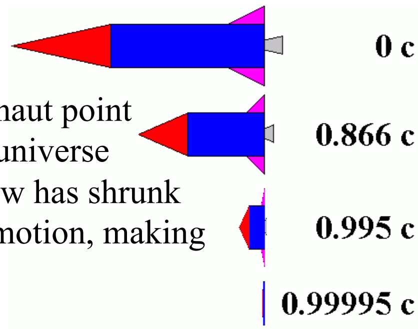
Moving objects are shorter in the direction of relative motion



http://www.physicsclassroom.com/mmedia/specrel/lc.html

Length Contraction

- This effect has some benefits:
  - Outside observers will measure that the length of the spaceship has shrunk.
    - This doesn't really help or harm us
  - But, from the astronaut point of view, the entire universe outside their window has shrunk in the direction of motion, making the trip shorter!
- It's all relative.



Question

Your best friend is going on a near light speed trip. When at rest you measure her spaceship to be 100 feet long. Now, she's in flight and you're on the Earth, and you measure her spacecraft to be

a) Exactly 100 feet long.
b) Less than a 100 feet long.
c) More than a 100 feet long.

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c) More than a 100 feet long.

Counterintuitive Result #2

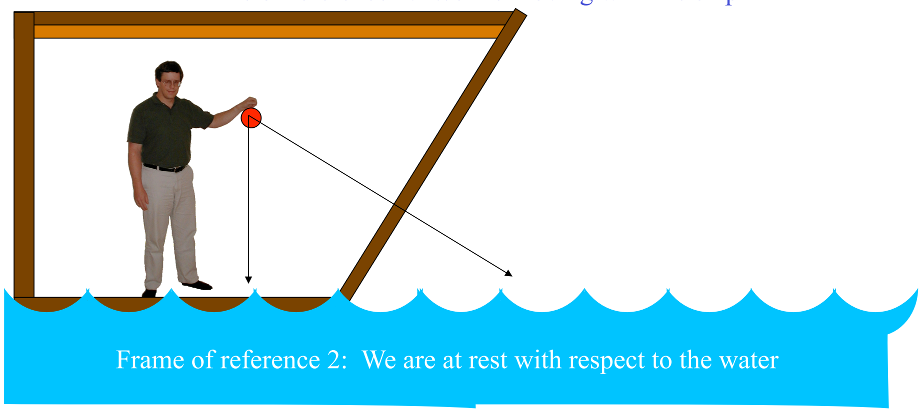
Clocks on Moving objects slow down

"Try not to watch the clock. It only makes the day go slower."

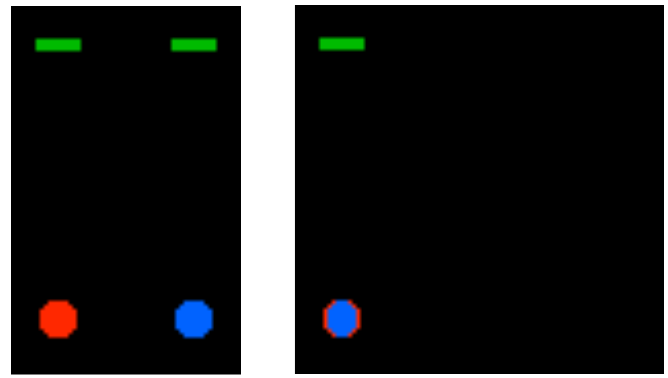
Galileo's ship thought experiment

No experiment within the ship's cabin can detect the ship's motion if the ship moves in the same direction at a constant velocity. This is still true, even when considering the speed of light.

Frame of reference 1: We are moving with the ship



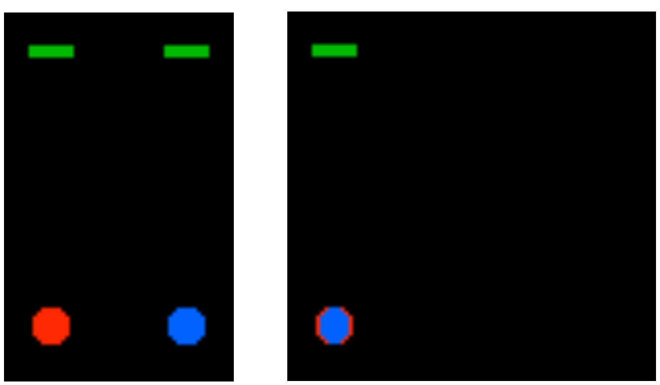
If the Ball is light?



A. Hamilton (Colorado)

Counterintuitive Result #2

Time appears to advance more slowly for moving objects (<u>time dilation</u>)

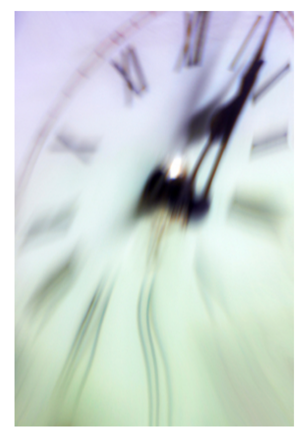


Red & blue at rest Blue moving to right

http://www.youtube.com/watch?v=KHjpBjgIMVk A. Hamilton (Colorado)

Time Dilation

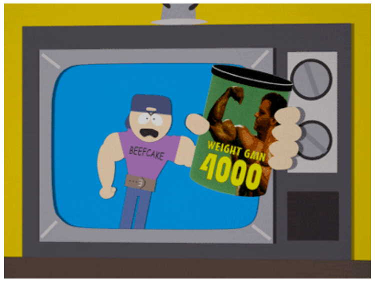
- The effects of time dilation are curious but not prohibitive for space travel
  - Astronauts will age less than the Earth-bound folks waiting for the return. Can spoil the homecoming celebrations.
  - The faster you go, the bigger difference between astronaut time and Earth time



- Example: Trip to the center of the Galaxy and back. Accelerate at 1g for the first half and decelerate for second half and you can go 30,000 ly in 20 years! But more than 30,000 years has elapsed on Earth!

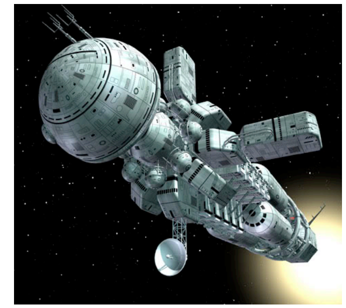
Counterintuitive Result #3

Mass increases for moving objects

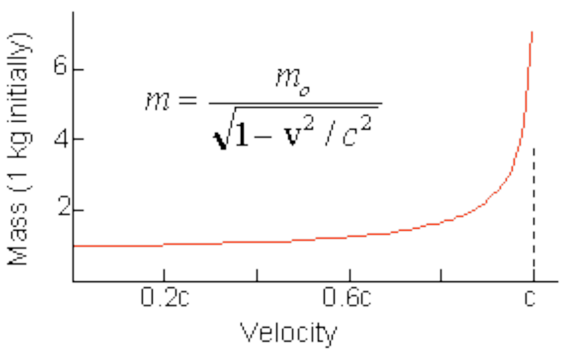


Mass Increase

- The increase of effective mass (and kinetic energy) with velocity makes acceleration and deceleration more difficult if you intend to travel close to "c"
  - This translates to very costly starflight in terms of required energy.
  - And now the interstellar dust that you strike at relativistic speeds appear as larger mass.
  - For 99% speed of light travel, 5.5 meters of shield would erode every year.



The gamma factor and mass:



Infinite Mass!!!!

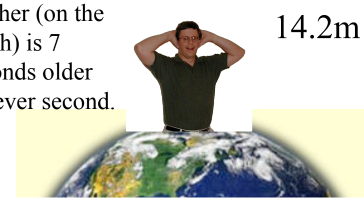
So, what does that mean?

- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship measures 100m long, but someone on the Earth would measure the spaceship to only be 14m long.
- As you speed by the Earth your clock would tick 1 second, and an observer would tick about 7 seconds.

0.99 c

14.2m

Paul's Twin brother (on the Earth) is 7 seconds older for ever second.

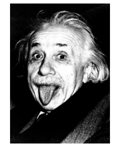


And Paul's measured mass increased by a factor of 7.

Question

You are traveling near light speed. You see the Earth slide past your window. You notice that you left a clock (readable from space), and for every second that pasts on the spacecraft

a) Exactly 1 second pasts on Earth.
b) Less than a second pasts on Earth.
c) More than a second pasts on Earth.



Special Relativity Summary

All motion is relative, except for that of light. Light travels at the same speed in all frames of reference.

Objects moving close to the speed of light appear to shrink in the direction of travel.

Time appears to advance more slowly for objects moving close to the speed of light.

Mass of the moving object appears to rapidly increase as an objects moves close to the speed of light.

Question

Okay, so length and time can change, then what exactly is a constant?

a) The speed of light.
b) The length of an iron pipe.
c) The time it takes for a photon to cross the Universe.
d) The speed of sound.
e) The speed of a class.. it is always too slow.

Rocket Science

Momentum and Rockets

- Rockets are propelled by the same principle (on Earth or in space):
  - Rocket fuel releases tremendous energy.
  - The by-product is directed out the back of the rocket.
  - The rocket is pushed forward just like the “rocket” chair.
  - The high momentum is created by high velocity and a large mass of fuel ejected.

http://bagocrap.1accesshost.com/drawings/rocketwheelchair.gif

The Rocket Principle

- Conservation of momentum (mass x velocity):
  - Sit in a chair with wheels and throw a heavy ball.
  - You and the chair will recoil in the opposite direction
  - This is the famous “action-reaction” mechanism. Newton’s 3rd law.

The Rocket Principle

- Conservation of momentum (mass x velocity):
  - Your “rocket” chair would work by throwing a heavy ball
    - Achieving a high momentum with a large mass
  - Or, you could throw a light baseball, but very fast!
    - Achieving a high momentum with a large velocity
    - This is why a gun recoils when its fired.

Rocket Man: 4 Quantities

1. V_e : the exhaust velocity, usually in km/s.

Rocket Man: 4 Quantities

2. Thrust : force exerted by the exhaust (Newtons or pounds).

$$Thrust = \frac{mass}{\sec} \times V_e = Force = mass \times acceleration$$

Rocket Man: 4 Quantities

3. Mass Ratio :

$$R_M = \frac{M_{total}}{M_{payload}} = \frac{M_{fuel} + M_{payload}}{M_{payload}}$$

This should be low: close to 1 is best. Of course, it depends on how fast you want to go & how efficient the fuel. And usually, the faster you go, the larger the R_m. But, the larger the R_m the more inefficient. Consequently, we need a fuel that produces more thrust per unit mass of fuel.

Rocket Man: 4 Quantities

4. Specific Impulse:

$$s.i. = \frac{thrust}{Fuel\ Rate} = \frac{\frac{mass}{s} \times V_e}{\frac{mass}{s}}$$

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In metric $$= \frac{Newtons}{\left(\frac{kg}{s}\right)}$$

In British Engineering System $$= \frac{Pounds}{\left(\frac{Pounds}{s}\right)} = seconds$$

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In British Engineering System

$$= \frac{Pounds}{\left(\frac{Pounds}{s}\right)} = seconds$$

The units have traditionally been in seconds. But it is a little confusing, and has nothing to do with time.

It is a property of the fuel and engine design. Sort of like octane rating in gasoline–
a large s.i. is a good thing.

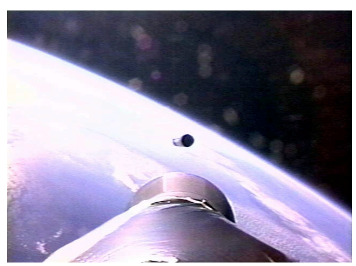
How's it work?

- For rocket to take-off, its thrust must be greater than its weight (force up > force down).
- In addition, the rocket needs to escape the Earth's pull.
- That means that the rocket velocity must exceed the Earth's escape velocity (11.2 km/s or 7 miles/s).
- Humans have never built a rocket that can do this!!!

http://www.eos.ucar.edu/mopitt/instr/rocket.jpg

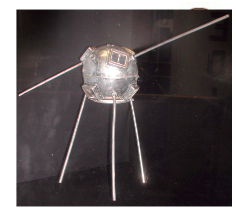
What you talking 'bout Willis?

- Humans have never built a rocket that can escape the pull of Earth?
- No, that's why we have to use multistage rockets.
- Once the fuel from the first stage is spent, it's dropped.
- Then, the next stage is higher up, so the escape speed is less than from ground level.
- To escape the Earth's gravity many stages are necessary.

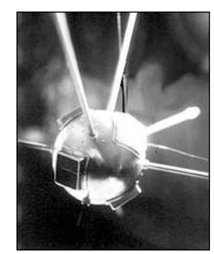


http://www.utahredrocks.com/stardust/launch6.jpg

Not Good



- Multistage rockets are wasteful.
- The Mass Ratio can be huge!
- The first US satellite was the Vanguard launched on March 17, 1958. (Still in orbit!)
- 6.4 inch diameter with 2 radio transmitters.
- Weighed 3 lbs = 1.4 kg.
- Rocket mass was 36,000 kg.
- $R_M = \frac{36000 + 1.4}{1.4} = 25{,}715 >> 1$
- Major ventures in space impossible with R_M this large.



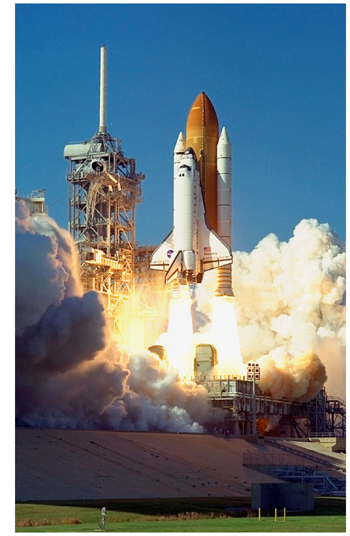
http://www.bafsat.com/h3.html

Kiss and Make Better

- Can lower the mass ratio by increasing either the exhaust velocity or the specific impulse.
- Shuttle is **state-of-the-art**.
- Payload = 2.95×10^4 kg
- $M_{takeoff} = 2 \times 10^6$ kg
- $R_M = \dfrac{2\times10^6 + 2.95\times10^4}{2.95\times10^4} = 67.8$

Kiss and Make Better

- Shuttle thrust is 29×10^6 N with 80% from solid rocket boosters– they fall off at 40km.
- s.i. = 455 seconds
- Good, but not good enough to leave Earth's orbit (shuttle orbits @185 km)



Combustion Rocket Terminology

- A *fuel* is combusted, which means it 'burns', which means it reacts with oxygen.
- In space, there is no oxygen around, so the rocket must carry its own source of oxygen. Also known as an *oxidizer*.
- This forms a new waste compound called a *propellant* that is ejected out the back, thrusting the rocket forward by conservation of momentum.

Propellant-based

- Eject something backwards, you go forwards. **Newton's da man!**
  - Chemical : Burn fuel, exhaust is propellant
  - Nuclear : Reactor heats propellant
  - Electric/Ion : Ionize fuel atoms, push them out with electric fields
  - Anti-matter : Use energy from matter-antimatter annihilation to generate light thrust.

Fuels

- Look at the "octane" of various fuels available today.
- $H_2 + O_2 \rightarrow$ s.i. = 455 sec
- O_2 + hydrazine (N_2H_4) $\rightarrow$ s.i. = 368 sec
- H_2 + fluorine (F) $\rightarrow$ s.i. = 475 sec
  - But exhaust gas is hydrofluoric acid
- **Note: No chemical fuel can achieve s.i. > 500 sec.**

Rocket Combustion: Chemical Fuels

1. Petroleum : Refined kerosene with LOX (liquid oxygen) oxidizer. *(Saturn V first stage)*
2. Cryogenic : Ultra cold hydrogen fuel with LOX oxidizer. Propellant is…water! *(Space Shuttle Main Engines)*
3. Hypergolic: A fuel and oxidizer that combust with no need for ignition. Fuel can be "monomethyl hydrazine" (MMH) and the oxidizer is "nitrogen tetroxide" (N_2O_4). *(Space Shuttle Orbital Maneuvering Subsystem)*
4. Solid: Oldest form (like in model rockets), exists in solid form, hard to stop burning. Has oxidizer mixed together with fuel. *(Space Shuttle Boosters– SRBs)*

http://www-pao.ksc.nasa.gov/kscpao/nasafact/count2.htm

Petroleum rocket fuel in action

The mighty Saturn V 1st stage (launched Apollo 11).

http://vesuvius.jsc.nasa.gov/er/seh/movies.html#Saturn

http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg

Petroleum rocket fuel in action

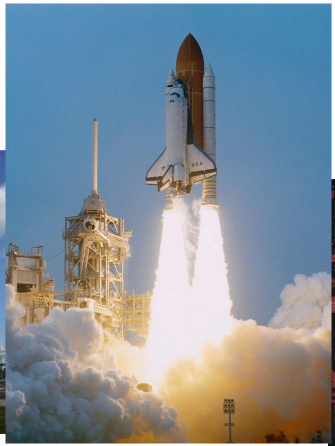
The mighty Saturn V 1st stage (launched Apollo 11).

http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg

Cryo fuel in action

The Shuttle's main engines!

http://www.slivka.com/Trips/ShuttleLaunch/pics/LOX_tank_750,000_gallons_at_launch_complex_39A_T.jpg



http://engineering.newport.ac.uk/StaffPer/StaffEngPer/DevansPer/Space-Shuttle.JPG

http://www.physicscurriculum.com/Photos/Space3.JPG

Shuttle Launch

Shuttle Links

http://www-pao.ksc.nasa.gov/kscpao/shuttle/countdown/sts100/liftoffvideo.htm

http://science.ksc.nasa.gov/shuttle/missions/sts-90/vrtour/checkpoint.html

http://imedia.ksc.nasa.gov/shuttlesim/index.html

Hypergolic

Space shuttle orbital maneuvering system uses hypergolic fuel

Solid fuels:

Space shuttle launch uses solid fuel (like model rocket).

1.3 Mlbs at launch. The fuel for each solid rocket motor weighs approximately 1.1 Mlbs. The inert weight of each SRB is approximately 192,000 pounds.

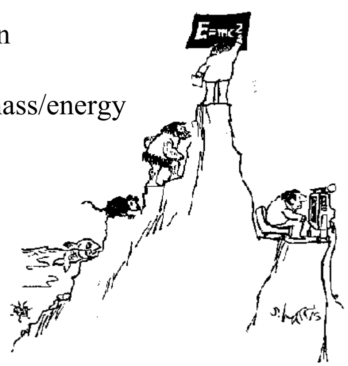
- Ammonium perchlorate (oxider)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)

Fuel Efficiency

- To really think about interstellar travel or even going to Mars, we need the most bounce for the ounce:
  - Need to carry (probably MUCH) fuel
  - Must be very thrifty about efficiency
  - In other words, if we are going to carry fuel mass on a ship, we had better get as much energy from it as possible!

$E=mc^2$

- Can relate mass to energy, i.e. the most energy one can get from a piece of mass, no matter what you do
- A useful unit of mass/energy in particle physics is the "***electron volt***" or "eV"
- A proton "weighs" about 1 billion electron volts: 1GeV
- So a H atom is about 1 GeV of mass/energy



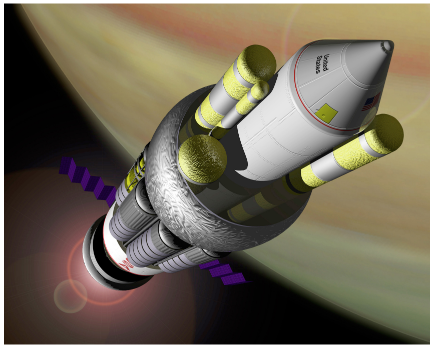
http://www.owlnet.rice.edu/~spac205/E=mc2.gif

Fuel Efficiency

- Chemical fuel (like burning wood or rocket fuel) one only gets a few eV of energy from each atom or molecule
  - In other words, only about 1 billionth of the total mass of the chemical agents gets converted into energy!
- Nuclear fission gives off a few MeV for each nucleus that fissions:
  - So, about one thousandth of the total mass gets converted into energy!
  - Better than chemical by a factor of a million!
- Nuclear fusion reaction can produce about 10MeV from a light nucleus
  - So, the efficiency is about one hundredth!
  - Getting better!

Project Orion

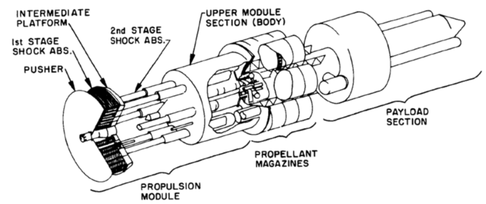
- A spacecraft powered by nuclear bombs– nuclear fission.
- Idea was sponsored by USAF in 1958
- Physicist Freeman Dyson took a year off from Princeton to work on idea
- Sounds crazy now… but a real project



http://www.daviddarling.info/encyclopedia/O/OrionProj.html

Project Orion

- You dropped hydrogen bombs wrapped in a hydrogen rich jacket out the rear of a massive plate.
- Detonate 60 meters away, and ride the blast-- an atomic pogo stick.
- 0.1 kton bomb every second for take off, eventually tapering to one 20 kton bomb every 10 sec.



http://en.wikipedia.org/wiki/Project_Orion_%28nuclear_propulsion%29

Project Orion

- s.i. theoretically around 10,000 to one million seconds
- Limited to about 0.10c.
- But, it is a “dirty” propulsion system.
- A 1963 treaty banned nuclear tests in the atmosphere, spelled the end of "Orion".
- Still argued to be the best rocket we could build today.

http://www.daviddarling.info/encyclopedia/O/OrionProj.html