PHYS:1200 FINAL EXAM

- **FINAL EXAM**: Wednesday December 17, 12:30 P - 2:30 P in LR-1 VAN
- FE covers Lectures 23 – 36
- The study guide, formulas, and practice final exam questions are posted on the Exam Information Link below.
- We will review the practice final exam questions on Wed. Dec. 10, and Friday Dec. 12.

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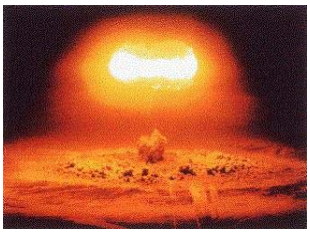
L 36 Modern Physics - 4

- Nuclear physics ←
  - what's inside the nucleus and what holds it together ←
  - what is radioactivity, half-life ←
  - carbon dating ←
- Nuclear energy
  - nuclear fission
  - nuclear fusion
  - nuclear reactors
  - nuclear weapons



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Radioactivity

- Some nuclei are unstable and spontaneously emit particles at random times
  - Alpha particles ${}_2^4He$ (helium nucleus)
  - Beta particles – energetic electrons
  - Gammas - energetic photons (higher than x-rays)
- The beta particles (electrons) come from a process called beta decay, in which a neutron decays into a proton, an electron and an antineutrino (note that charge is conserved!)

$$ {}_o^1n \rightarrow {}_1^1p^+ + e^- + \bar{\nu} $$

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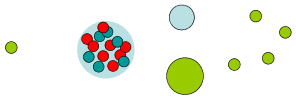
Nuclear reactions: $E = mc^2$

Energy is released in the fission (breakup) of a heavy nucleus by fast neutron bombardment



$$ {}_0^1n + {}_{94}^{239}Pu \rightarrow {}_{38}^{96}Sr + {}_{56}^{143}Ba + {}_0^1n $$

mass = 240.06 units mass = 239.86 units

The extra mass is converted into kinetic energy, which is mostly in the neutrons.

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Biological effects of nuclear radiation

- Nuclear reactions can produce alphas, betas, neutrons and gamma radiation (particles or photons)
- Nuclear radiation is ionizing radiation, i.e., energetic enough to knock electrons out of atoms or molecules
- *Ionizing radiation* is potentially harmful to humans because the ionization it produces can alter significantly the structure of molecules within a living cell which can lead to alterations of the cell (make them cancerous) or to the death of the cell

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Hazards of radiation

- The hazards of radiation can be minimized by limiting overall exposure
- The effects of absorbed doses or ionizing radiation is measured in a unit called the rem.
- The effects of radiation exposure are
  - Short term or acute effects appearing within a matter of minutes of exposure
  - Long-term effects that may appear in years, decades or even in future generations

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Average radiation doses received by a US resident

Source of radiation	dose in mrem/yr*
Natural Background radiation	
Cosmic rays	28
Earth and air	28
Internal radioactive nuclei	39
Inhaled radon	200
Man-made radiation	
Medical / dental x-rays	39
Nuclear medicine	14

*Current federal standards limit exposure to 500 mrem/yr

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Radiation sickness

- This is the general term applied to the acute effects of radiation
- A dose less than 50 rem causes no short term ill effects
- A dose of 50 – 300 rem at one time brings on radiation sickness
- A whole body dose of 400 – 500 rem is lethal for about 50% of people exposed
- Whole body doses greater than 600 rem results in death for almost all individuals

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Nuclear Physicists

Otto Hahn and Lise Meitner discovered fission. Only Hahn won the Nobel Prize. Meitner should also have won.

Marie Curie discovered radioactivity. First woman to win a Nobel Prize. Won 2 Nobel prizes in Physics and Chemistry.

Enrico Fermi "Father of the Atomic bomb" Won Nobel prize for discovering new radioactive elements.

Edward Teller "Father of the Hydrogen bomb" Convinced Pres. Reagan to pursue the "Star Wars" project.

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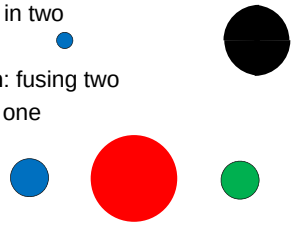
Energy from the nucleus

- Huge amounts of energy are given off in two nuclear processes
  - **Nuclear fission**: splitting a heavy nucleus in two
  - **Nuclear fusion**: fusing two light nuclei into one



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A lot of energy from a little mass

- The energies released when a large nucleus undergoes fission or small nuclei undergo fusion are enormous compared to chemical energies (e.g. burning fossil fuel)
- When Uranium splits apart about 0.1% of its mass is converted into energy
- Pound for pound, nuclear reactions release about 10 million times more energy than chemical reactions
- 1 pound Uranium → 1 million gallons of gasoline

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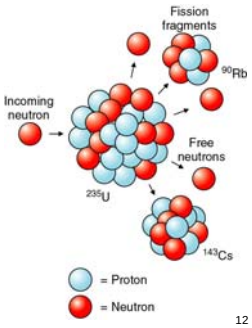
Splitting the atom→ Nuclear Fission

- To split a uranium nucleus apart takes energy
- A neutron hitting a uranium nucleus can cause it to split
- A neutron can split U-235 into Cs-143 and Rd-90 plus a *few extra neutrons*



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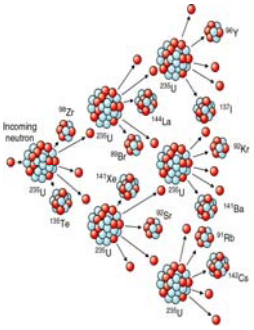
The nuclear chain reaction

- When U-235 splits, on average 2.5 neutrons are released
- These neutrons can then go on to cause other U-235's to split, this resulting in a **chain reaction**
- This can result in a catastrophic process with enormous energy released.



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Reactor *or* Bomb

- If the energy released in a nuclear chain reaction is allowed to proceed in a controlled way, then this can be used as an energy source → *nuclear reactor*
- If the chain reaction occurs in an uncontrolled manner then you have → *atomic bomb*
- Enrico Fermi produced the first nuclear reactor under the west stands of Stagg Field at the University of Chicago in 1942

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Electricity generation by nuclear power

Steel and Concrete Containment vessel

Percentage of electricity produced by nuclear power

France: 77%
Belgium: 54%
Slovakia: 54%
Switzerland: 41%
Sweden: 36%
USA: 19%
Germany: 18%
Japan: 18%
Russia: 18%
UK: 16%
Canada: 15%
Argentina: 7%
China: 2%

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Nuclear reactors

- The fuel elements contain the fissile fuel in the form of rods of 1 cm diameter. There may be thousands of such rods stacked together in the reactor core
- The most common fuel is enriched U-235
- Some type of moderator material is also used to slow down the neutrons to make their capture more efficient

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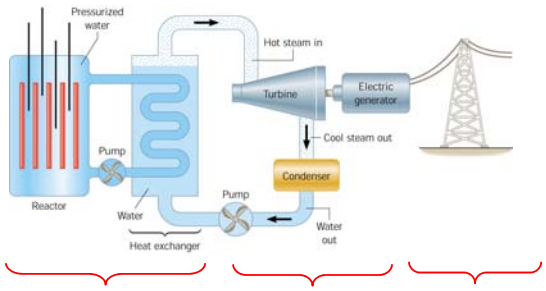
A nuclear power plant



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Reactor operation

- The reactor is usually operated in the so-called *critical* state in which each fission leads to only one additional fission.
- In the critical state the reactor produces a steady output of electrical energy
- The reactor is designed not to go into the *supercritical* state – in this state the reactor produces an uncontrolled and increasing amount of energy which can cause it overheat and lead to meltdown.

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Controlling the nuclear reactor

- To keep the reactor in the critical state the operators adjust the *control rods*
- The control rods can be moved into or out of the reactor core. They contain an element, such as cadmium or boron which absorbs neutrons.
- If the reactor is getting too hot, the control rods are pushed into the core to slow down the chain reaction
- The heat generated within the fuel rods is carried away by water surrounding the rods

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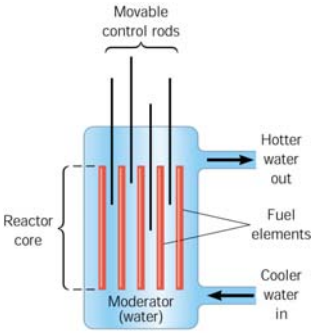
Reactor core



- To start the reactor, the control rods are pulled out of the core
- To stop the reactor, the control rods are pushed into the core
- Inside a concrete containment vessel

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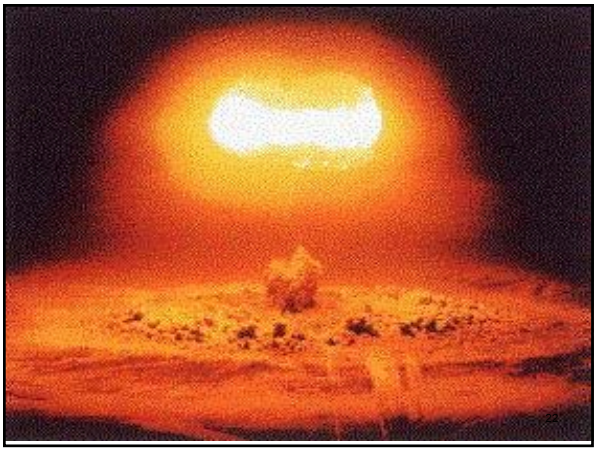
Pros and Cons of Nuclear energy

ADVANTAGES	DISADVANTAGES
• Plentiful fuel • no greenhouse gases • no poisonous emissions • non-polluting • efficient power production	• must deal with nuclear waste • possibility of catastrophic accident with long term effects* • expensive to build • can be used to enrich uranium for bombs

* -- US – 1979, Three mile Island, Pennsylvania
-- World- 1986, Chernobyl, Ukraine (80 killed within one week of accident)
-- Japan -2011 caused by Tsunami
negative spin – big disaster – no more nuclear power plants
positive spin – even with Tsunami, no one killed, build more plants[21]



The atomic (fission) bomb

- a critical mass of fissionable material is needed
- Natural uranium contains ^{238}U and 0.7% ^{235}U, but only ^{235}U is fissionable. In the enrichment process, the ^{235}U and ^{238}U are separated. Weapons-grade uranium requires enrichment to > 20%.
- if a critical mass can be achieved than an self-sustained uncontrolled reaction occurs
- To achieve critical mass (60 kg), 2 lumps (7 inch diameter ball) of a non-critical mass of U-235 are brought together quickly using a cannon
- When the U-235 becomes supercritical, a catastrophic fission will quickly turn into a fireball

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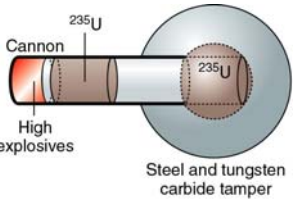
Little Boy (Uranium bomb)



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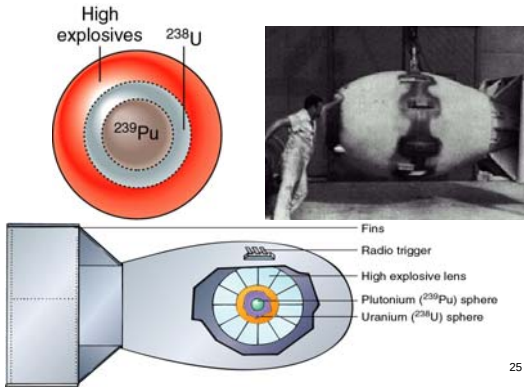
FAT MAN (Plutonium bomb)



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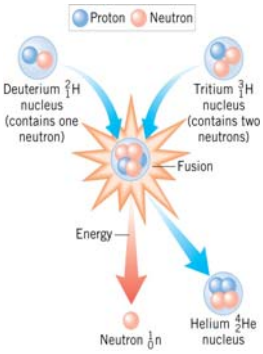
Nuclear Fusion



→ Two light nuclei (D & T) are combined into one (He) with a large release of energy

→ If this is done with a a large number of nuclei, the energy is released catastrophically as a *Hydrogen Bomb*

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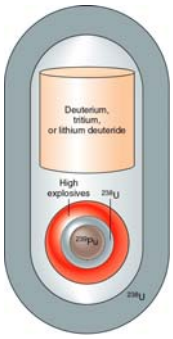
The Hydrogen (thermonuclear fusion) **Bomb**



- A fusion bomb releases energy by fusing deuterium with tritium nuclei to form helium and neutrons
- To achieve this, the hydrogen must be heated to 100 million C using a fission bomb → thermonuclear
- Thermonuclear fusion is what powers the stars

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Effects of a nuclear explosion

- The released neutrons produce the fireball by heating everything around them
- The ultra hot fireball produces an intense flash of light, x-rays and gamma rays
- The explosion creates a huge pressure surge → blast wave that flattens everything within miles of ground zero
- Long after the blast there is the fallout → the creation and release of radioactive nuclei that are carried away in the air

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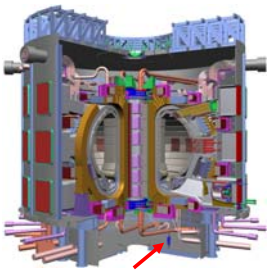
Controlled thermonuclear fusion



International Thermonuclear Experimental Reactor (ITER)

- Nuclear reactor using nuclear fusion energy
- Safer than fission reactor
- Fuel (D, T) can be obtained from seawater
- Will heat Tritium gas to 100,000,000 K
- Test reactor being built in France; collaboration of seven countries: EU, IN, JP, CH, RU, SK, US.

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