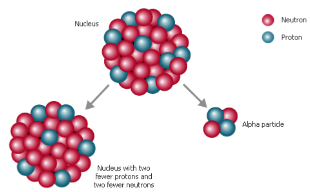
PH300 Modern Physics SP11



I know not with what weapons World War III will be fought, but World War IV will be fought with sticks and stones.
- A. Einstein

4/14 Day 23:
Questions?
Radioactivity & STM

Next Week:
Hydrogen Atom
Periodic Table
Molecular Bonding

Final Essay

Three options:

A) There is only a final paper, and no essay portion on the final.

B) People may choose, but those who turn in a paper will have more time on M/C than those who do not.

C) No final paper, only an essay portion on the exam for everyone.

Recently:
1. Quantum tunneling
2. Alpha-Decay
3. Radioactivity

Today:
1. Radioactivity (cont.)
2. Scanning Tunneling Microscopes
3. Other examples…

Next 2 weeks:
1. Schrodinger equation in 3-D
2. Hydrogen atom
3. Periodic table of elements
4. Bonding

3

Energy:

1 fission of Uranium 235 releases:
~10^{-11} Joules of energy

1 fusion event of 2 hydrogen atoms:
~10^{-13} Joules of energy

Burning 1 molecule of TNT releases:
~10^{-18} Joules of energy

1 green photon:
~10^{-19} Joules of energy

Dropping 1 quart of water 4 inches ~ 1J of energy

Useful exercise… compare this volume of TNT, H2, and U235

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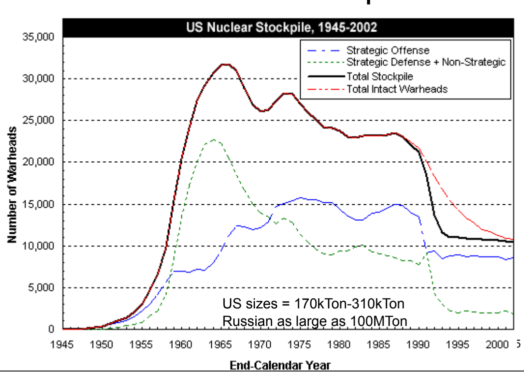
US Nuclear weapons



In the first plutonium bomb a 6.1 kg sphere of plutonium was used and the explosion produced the energy equivalent of 22 ktons of TNT = 8.8×10^{13} J.

17% of the plutonium atoms underwent fission.

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In atomic bomb, roughly 20% of Pl or Ur decays by induced fission. This means that after an explosion there are…

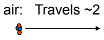
a. about 20% fewer atomic nuclei than before with correspondingly fewer total neutrons and protons,
b. 20% fewer atomic nuclei but about same total neutrons and protons.
c. about same total neutrons and protons and more atomic nuclei.
d. almost no atomic nuclei left, just whole bunch of isolated neutrons and protons
e. almost nothing of Ur or Pl left, all went into energy.

ans. c. Makes and spreads around lots of weird radioactive "daughter" nuclei (iodine etc.) that can be absorbed by people and plants and decay slowly giving off damaging radiation.
Lots of free neutrons directly from explosion can also induce radioactivity in some other nuclei.

Alpha particles: helium nuclei

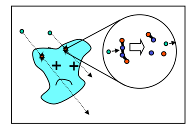
- most of radiation is this type
- common is Radon (comes from natural decay process of U^{238}), only really bad because Radon is a gas .. Gets into lungs, if decays there bad for cell.

In air: Travels ~2 cm ionizing air molecules and slowing down …



eventually turns into He atom with electrons

If decays in lung, hits cell and busts up DNA and other molecules:

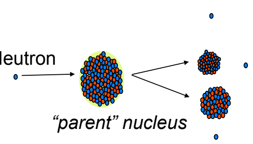


Usually doesn't get far -- because it hits things

Beta particles:

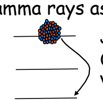
energetic electrons … behavior similar to alpha particles, but smaller and higher energy

Sources of Gamma Radiation



- *two smaller nuclei*
- *few extra free neutrons*
- ***LOTS OF ENERGY!!***
- *(+sometimes other bad stuff)*

"daughter" nuclei – come out in *excited* nuclear energy state
…. Give off gamma rays as drop to lower energy.

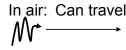


Jumps down in energy …
Gives off gamma ray…
VERY HIGH ENERGY PHOTON

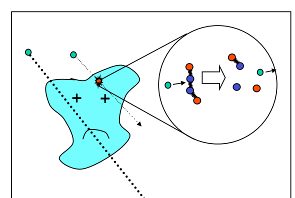
gamma rays: high-energy photons

- So high energy can pass through things (walls, your body) without being absorbed, but if absorbed really bad!

In air: Can travel long distances until absorbed

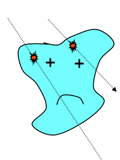


In body, *if* absorbed by DNA or other molecule in cell … damages cell… can lead to cancer.



Most likely

If pass through without interacting with anything in cell then no damage.



Also break DNA→ cancer

But also can cure cancer- Concentrate radiation on cancer cells to kill them.

An odd world…

You find yourself in some diabolical plot where you are given an alpha (α) source, beta (β) source, and gamma (γ) source. You must eat one, put one in your pocket and hold one in your hand. Your choices:

a) α hand, β pocket, γ eat
b) β hand, γ pocket, α eat
c) γ hand, α pocket, β eat
d) β hand, α pocket, γ eat
e) α hand, γ pocket, β eat

α - very bad, but easy to stop -- your skin / clothes stop it
β - quite bad, hard to stop -- pass into your body -- keep far away
γ - bad, but really hard to stop--- rarely rarely gets absorbed
Me--- I pick (d)---

Results of radiation

~4,000 counts/min = .002 Rem/hr

dose in rem = dose in rad x RBE factor (relative biological effectiveness)

RBE = 1 for Υ, 1.6 for β, and 20 for α.

A rad is the amount of radiation which deposits 0.01 J of energy into 1 kg of absorbing material.

source/situation	dose	effect
neutron bomb blast	>100,000 rem	immediate death
Chernobyl firefighter	400 rem	50% probability of death within 30 days
space shuttle astronaut	25 rem	due to increased cosmic ray exposure
accidental exposure	10 rem	blood changes barely detectable
max. allowed exposure for radiation workers	5 rem over 1 year	no blood changes detectable, negligible increased risk of cancer.
radon exposure (avg. US)	200 mrem = 0.2 rem/yr	probably none
other terrestrial sources	40 mrem/year	probably none
cosmic radiation (sea level)	30 mrem/ year	probably none
single chest x-ray	20 mrem	probably none
nuclear fallout[+]	3 mrem/year	probably none
nuclear power plant leakage	0.01 mrem/year	probably none
total average dose (US citizens)	350 mrem/year	probably none

+ primarily due to atmospheric testing of nuclear weapons by US and USSR in the 50's and early 60's, prior to the nuclear test-ban treaty which forbid above-ground testing.

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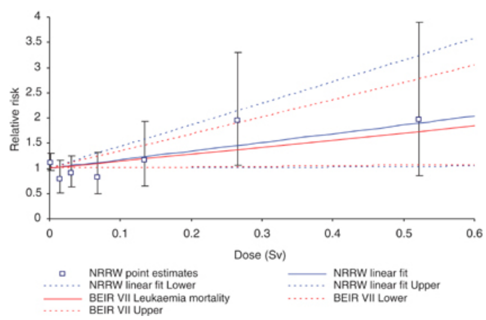
Effect	Short-Term Risk:	Dose
Blood count changes		50 rem
Vomiting (threshold)		100 rem
Mortality (threshold)		150 rem
$LD_{50/60}$ (with minimal supportive care)		320 – 360 rem
$LD_{50/60}$ (with supportive medical treatment)		480 – 540 rem
100% mortality (with best available treatment)		800 rem

Long-Term Risk:



1 Sievert = 100 rem

Each of these contributes the same increased risk of death (+1 in a million):

Smoking 1.4 cigarettes in a lifetime (lung cancer)

Eating 40 tablespoons of peanut butter (aflatoxin)

Spending two days in New York City (air pollution)

Driving 40 miles in a car (accident)

Flying 2500 miles in a jet (accident)

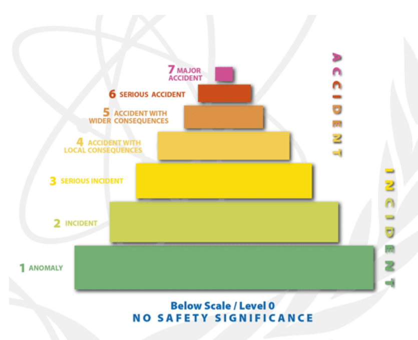
Canoeing for 6 minutes (drowning)

Receiving a dose of 10 mrem of radiation (cancer)

Substance	Half-Life
Polonium-215	0.0018 s
Bismuth-212	1 hour
Iodine-131	8 days
Cesium-137	30 years
Plutonium-239	1620 years
Uranium-235	710 million yrs
Uranium-238	4.5 billion yrs

Greatest danger from intermediate half-lives!

The International Nuclear and Radiological Event Scale



The highest cesium-137 levels found in soil samples in *some* villages near Chernobyl were 5 million Bq/m^2.

(1 Bequerel = 1 decay/second)

March 20: Similar levels of cesium-137 measured in the soil at a location 40 km northwest from Fukushima plant.

April 12: Strontium-90 (half-life: 30 years) found near Fukushima plant.

If preliminary information is correct, Fukushima could **already** the worst nuclear disaster in history..

Rest of today:

other applications of tunneling in real world

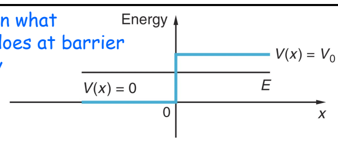
Scanning tunneling microscope (STM):

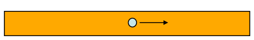
how QM tunneling lets us map individual atoms on surface

Interesting example not time to cover but in notes:

- Sparks and corona discharge (also known as field emission) electrons popping out of materials when voltage applied.
- Many places including plasma displays.

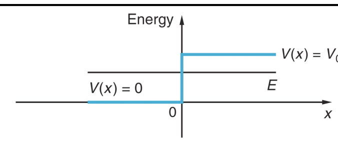
warm up on what electron does at barrier then apply





If the total energy E of the electron is LESS than the work function of the metal, V_0, when the electron reaches the end of the wire, it will…

A. stop.
B. be reflected back.
C. exit the wire and keep moving to the right.
D. either be reflected or transmitted with some probability.
E. dance around and sing, "I love quantum mechanics!"

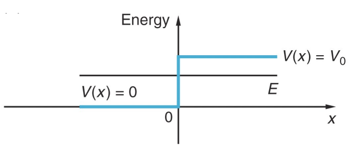


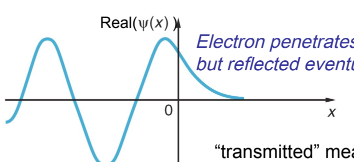
If the total energy E of the electron is LESS than the work function of the metal, V_0, when the electron reaches the end of the wire, it will…

Quantum physics is not so weird that electron can keep going forever in region where V>E. Remember that ψ decays exponentially in this region!

A. stop.
B. $\boxed{\text{be reflected back.}}$
C. exit the wire and keep moving to the right.
D. either be reflected or transmitted with some probability.
E. dance around and sing, "I love quantum mechanics!"

Once you have amplitudes,can draw wave function:



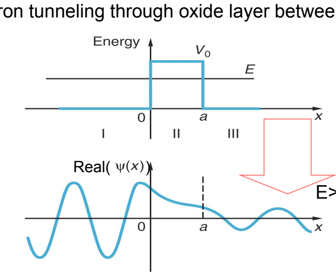


Electron penetrates into barrier, but reflected eventually.

"transmitted" means continues off to right forever. Wave function not go down to zero.

Can have transmission only if third region where solution is not real exponential!

(electron tunneling through oxide layer between wires)

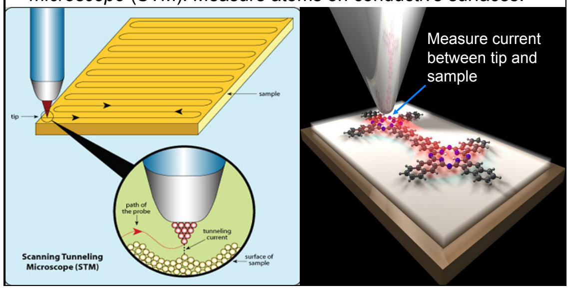


E>P,

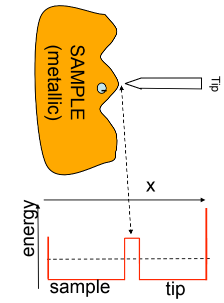
Ψ(x) can live! electron tunnels out of region I

Application of quantum tunneling: Scanning Tunneling Microscope → 'See' single atoms!

Use tunneling to measure very(!) small changes in distance.
Nobel prize winning idea: Invention of *scanning tunneling microscope* (STM). Measure atoms on conductive surfaces.



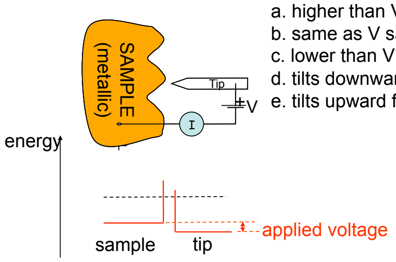
Look at current from sample to tip to measure gap.



Electrons have an equal likelihood of tunneling to the left as tunneling to the right

-> no net current

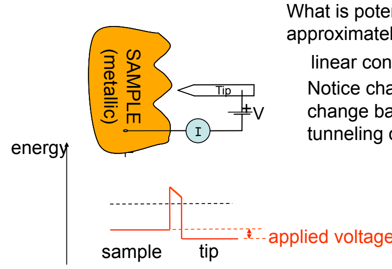
Correct picture of STM-- voltage applied between tip and sample. Holds potential difference constant, electron current.
Figure out what potential energy looks like in different regions so can calculate current, determine sensitivity to gap distance.



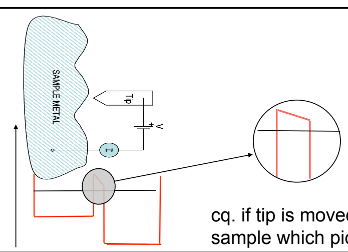
What does V tip look like?
a. higher than V sample
b. same as V sample
c. lower than V sample
d. tilts downward from left to right
e. tilts upward from left to right

Correct picture of STM-- voltage applied between tip and sample.

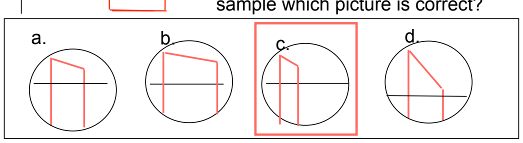
Potential energy in different regions so can calculate current, determine sensitivity to gap distance.



What is potential in air gap approximately?
linear connection
Notice changing V will change barrier, and hence tunneling current.



cq. if tip is moved closer to sample which picture is correct?



tunneling current will go up:
a is smaller, so $e^{-2\alpha a}$ is bigger (not as small), T bigger

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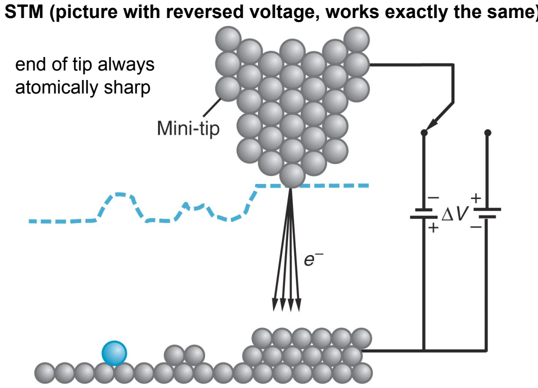
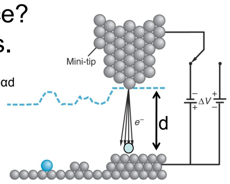
STM (picture with reversed voltage, works exactly the same)



How sensitive to distance?
Need to look at numbers.



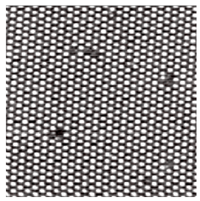
Tunneling rate: $T \sim (e^{-\alpha d})^2 = e^{-2\alpha d}$
How big is α?

$$\alpha = \frac{\sqrt{2m(V_0 - E)}}{\hbar}$$

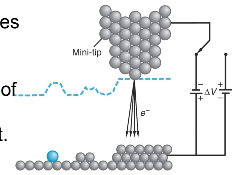
If V_0-E = 4 eV, $\alpha = 1/(10^{-10}$ m)

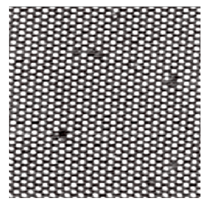
So if d is 3 x 10^{-10} m, $T \sim e^{-6} = .0025$
add 1 extra atom (d ~ 10^{-10} m),
how much does T change?

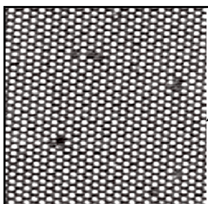
$T \sim e^{-4}$ =0.018
→Decrease distance by diameter of one atom:
→Increase current by factor 7!



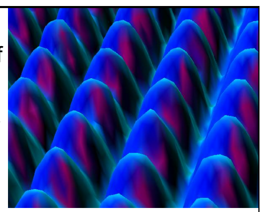
In typical operation, STM moves tip across surface, adjusts distance to keep tunneling current constant. Keeps track of how much tip moves up and down to keep current constant.
→Scan in x+y directions.
Draw a 2D map of surface

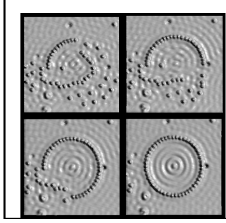




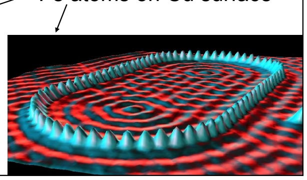


Crystal of Ni atoms

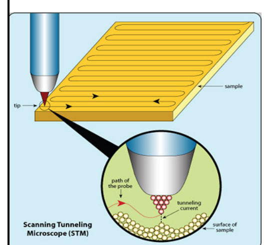




Fe atoms on Cu surface

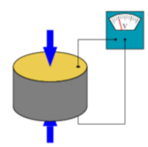


Scanning Tunneling Microscope



Requires very precise control of the tip position and height. How to do it?

With a piezoelectric actuator!



Typical piezo: 1V → 100nm displacement.
Applying 1mV moves tip by one atom diameter (~100pm)

Piezoelectric actuators and sensors are everywhere!

Buzzers in electronic gadgets and in smoke alarms.
Microphones in cell-phones.
Quartz crystals.
BBQ grills and lighters.
Knock sensors in car engines.
Seismology.
Concrete compactors
Sonar devices (Submarines, Robotics, Automatic doors)
Bones

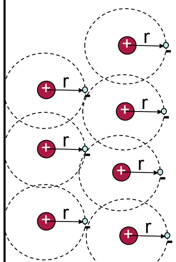
A more common manifestation of QM tunneling

Understanding electrical discharges.

A more common manifestation of QM tunneling

Understanding electrical discharges.

What electric field needed to rip electron from atom if no tunneling?



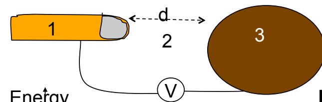
gas

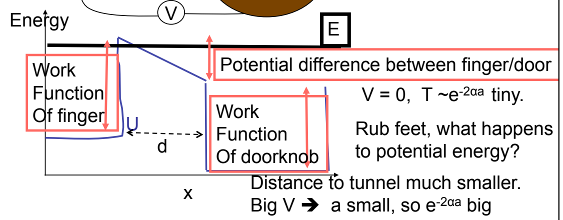
Applied E must exceed $E_{Nucleus}$

Typically, electric breakdown in air occurs at E ~ 2 MV/m

Get few million volts from rubbing feet on rug?

NO! Electrons tunnel out at much lower voltage.





V = 0, T ~$e^{-2\alpha a}$ tiny.

Rub feet, what happens to potential energy?

Distance to tunnel much smaller.
Big V ➔ a small, so $e^{-2\alpha a}$ big enough, e's tunnel out!