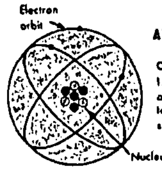


ATOM STRUCTURE

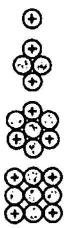
Outer orbit is only 1/100,000,000 inch across, nucleus is ten thousand times smaller than that

BASIC PARTICLES

Particle	Charge	Weight (mass units) Approx	Exact
Neutron	0	1	1.00893
Proton	+1	1	1.00758
Electron	−1	1/1800	

One lb of matter contains 273 trillion trillion nucleons (protons and neutrons)

LIGHT-ATOM NUCLEI



Isotope	Element	Protons	Neutrons	Nucleons
$_1H^1$	Hydrogen	1	0	1
$_2He^4$	Helium	2	2	4
$_3Li^7$	Lithium	3	4	7
$_4Be^9$	Beryllium	4	5	9

(Beyond helium, neutrons equal or exceed protons)

HEAVY-ATOM NUCLEI

Element	Isotope	Protons	Neutrons	Nucleons
Thorium	$_{90}Th^{232}$	90	142	232
Protactinium	$_{91}Pa^{231}$	91	140	231
Uranium	$_{92}U^{233}$	92	141	233
Uranium	$_{92}U^{235}$	92	143	235
Uranium	$_{92}U^{238}$	92	146	238
Neptunium	$_{93}Np^{239}$	93	146	239
Plutonium	$_{94}Pu^{239}$	94	145	239

Uranium 235 is completely defined as $_{92}U^{235}$ in which 92, atomic number of any uranium, indicates 92 protons and 235 is number of particles (protons plus neutrons) in this isotope. Also, 235 is the "mass number" of given isotope.

Basic particles, variously linked, form atom structures. Some change.

An atom is a tiny solar system, with more than 99.9% of its mass in the central "sun" or *nucleus*. This nucleus consists of *protons* and *neutrons*. Balancing each plus-charged proton in the nucleus is a negatively charged, rapidly revolving, *electron* "planet." Thus the whole atom is electrically neutral, although the nucleus is always positive.

In atomic energy work we deal only with the nucleus and commonly use the word "atom" to mean the nucleus. Two numbers identify any atom. Thus $_3Li^7$ means that any form of lithium has an atomic number of 3, because lithium atoms always have three protons. The *mass number* (7) is the total number of *nucleons* (protons plus neutrons) *in this* particular *isotope* (form) of lithium. If a lithium isotope had five neutrons its symbol would be $_3Li^8$. Tables above give data on some atoms, particularly the heavy ones, some of which are fissionable.

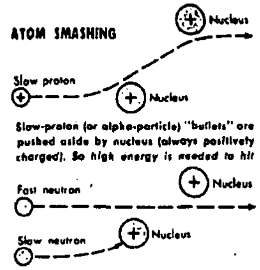
Natural radioactivity of certain heavy elements has long been known. Rate of disintegration is not affected by physical conditions or chemical action. Note in table above that radium is merely No. 7 in one radioactive series that started

URANIUM RADIOACTIVE SERIES

Element	Isotope	Radiation	Half life
Uranium	$_{92}U^{238}$	alpha	4.5 billion yr
Thorium	$_{90}Th^{234}$	beta	24 days
Protactinium	$_{91}Pa^{234}$	beta	1.14 minutes
Uranium	$_{92}U^{234}$	alpha	235,000 yr
Thorium	$_{90}Th^{230}$	alpha	80,000 yr
Radium	$_{88}Ra^{226}$	alpha	1620 yr
Radon	$_{86}Rn^{222}$	alpha	3.82 days

Alpha particle is a helium nucleus (2 protons and 2 neutrons). *Alpha emission* reduces mass number by 4 and atomic number by 2. *Beta particle* is an electron of negligible mass, so emission doesn't change mass number but raises atomic number by 1, changes neutron to proton.

ATOM SMASHING



Slow-proton (or alpha-particle) "bullets" are pushed aside by nucleus (always positively charged). So *high energy is needed to hit*

Neutron bullets, having no charge, are not repelled. If fast, they more often escape. If slow and closely aimed, they are trapped by powerful "adhesive" forces

MASS AND ENERGY INTERCHANGE

EINSTEIN: $E = MC^2$

where E = energy in ergs
M = converted mass, grams
C = velocity of light, cm/sec = 30,000,000,000

So one gram = 900 quintillion ergs
one lb mass = 11.4 billion kwhr
= 39 trillion Btu
= 30 quadrillion ft lb
= 2.73×10^{26} mass units

ATOMIC CONVERSION

Shorthand formula below says helium *"bullet" hitting nitrogen 14 knocks out* hydrogen atom and leaves oxygen 17:

	$_2He^4$ +	$_7N^{14}$ →	$_8O^{17}$ +	$_1H^1$
Protons	2	7	8	1
Neutrons	2	7	9	0
Nucleons	4	14	17	1

...naturally, or artificially, with a corresponding energy conversion

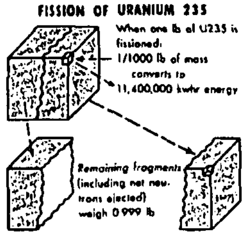
billions of years ago with uranium 238. *Half life* of a radioactive substance is time required for half the original weight to disintegrate into another nearby element or isotope. Half lives vary spectacularly from billions of years to a tiny fraction of a second. Thus it takes 4.5 billion years (table above) for half a given mass of U238 to change to thorium 234. Yet a given mass of Th234 takes only 24 days to change half itself to protactinium 234.

Artificial breakdown of atom structures is now carried out in "atom smashers." These hurl high-velocity particles at atomic nuclei. The "bullets" are charged particles (protons, electrons, helium nuclei, etc.) propelled by electric fields and steered by magnetic fields.

A neutron makes the best atomic bullet of all but cannot be directly accelerated in an atom smasher because it has no charge. But flying neutrons from exploded atoms are the sole means of propagating chain reactions in power reactors.

As given by Einstein's famous formula (above), a reduction in mass means a release of energy. Complete obliteration of one lb of matter would release 11.4 billion kwhr.

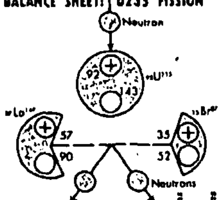
FISSION OF URANIUM 235



When U235 atom "splits", spare neutrons *are ejected. These can, in turn, split other* U235 atoms. If chain reaction continues until one lb is fissioned 1/1000 lb will be converted to energy

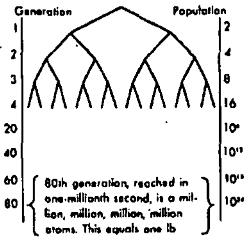
As shown in balance sheet (*right*) total particles after fission equal total before. Actual fission products and number of neutrons emitted vary from one fission to next

BALANCE SHEET: U235 FISSION



	Protons	Neutrons	Nucleons
BEFORE			
Impinging neutron		1	1
in U235	92	143	235
Total before fission	92	144	236
AFTER			
Larger fragment	57	90	147
Smaller fragment	35	52	87
Discharged neutrons		2	2
Total after fission	92	144	236

FAST (BOMB) CHAIN REACTION



Rate of growth for bomb with a reproduction factor of 2

When several pieces, each less than critical mass, come together quickly, chain reaction occurs at explosive speed until fragments separate enough to go below critical

"Splitting" heavy atoms yields vast energy and fission products...

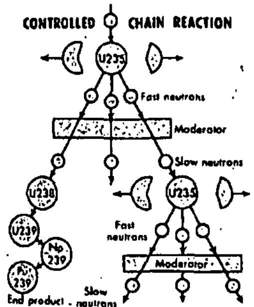
Only fissionable substance found in nature is uranium 235, a rare form of natural uranium (one part U235 to 139 parts U238). When hit by a neutron, the U235 nucleus splits into two lighter atoms and ejects several (2.5 average) spare neutrons. These new-born neutrons can, in turn, split other *U235 atoms. This chain reaction moves* to completion with explosive speed in a bomb or gradually in a power reactor.

Whether fission be fast or slow, complete fission of any mass of U235 converts 1/1000 part of the mass into energy, according to the Einstein formula.

Uranium bombs use concentrated U235, extracted at great cost from natural uranium. Power reactors may use natural uranium, or natural uranium plus U235 or plutonium.

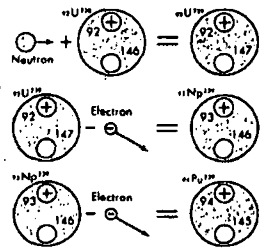
A lump of U235 smaller than a certain unrevealed *critical* mass will not maintain a chain reaction. This is because small *pieces have more surface* per unit of volume, hence let more neutrons escape without splitting atoms. The Smyth report states, vaguely, that the critical mass of pure U235 (a material much heavier than lead) is more than two lb and less than 200 lb.

CONTROLLED CHAIN REACTION



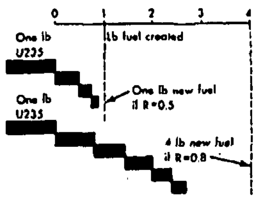
In natural-uranium reactor, "slow" neutrons split U235 atoms. Ejected fast neutrons are slowed by moderator, split other U235 atoms. Some neutrons are lost. Some, trapped by U238, start a chain ending with Pu

CONVERTING U238 TO PLUTONIUM



U238 captures neutron to become U239. In two steps, over several days, this decays to plutonium 239, equal to U235 as fuel. Note that electron ejection merely changes a neutron to a proton, doesn't change the number (239) of particles in the nucleus

ARITHMETIC OF BREEDING



R = Weight of Pu (plutonium) produced by "burning" one lb of U235 or Pu. If fuel produced is, in turn, burned to make more, and so on, theoretical total fuel produced is $R + R^2 + R^3 \ldots = 1 \div (1 - R) - 1$

Example: With reproduction rate (R) of 0.5, one lb of U235 makes one lb of new fuel; if R were 0.8, new fuel made would be 4 lb

...How fission occurs decides whether we have a bomb or a reactor

An atom bomb contains much more than the critical mass divided into several pieces, each less than critical. When these are brought together at high speed, a chain reaction occurs at explosive speed until fragments separate far enough to bring remaining mass below critical level.

Critical mass of *natural* uranium is infinite, so a natural-uranium reactor can't work without addition of something to boost effectiveness of highly diluted U235. *Moderators* do this by slowing down neutrons through multiple collisions. Slow neutrons are easily captured by nuclei, so make far more "hits." Low speed is enough to split loosely bound U235 atoms. Typical moderators are graphite, heavy water.

In any reactor containing U238 (usually many U238 atoms for each U235 atom) some flying neutrons will be captured by U238 atoms and will convert them by steps (see above) to plutonium. *This can be separated chemically* and used as a fissionable nuclear fuel equal to U235. Thus, indirectly, we can "burn" not only costly U235 but a substantial part of the plentiful U238. "Breeding," as outlined above, offers the possibility of burning the whole mass.