

PAN 2007

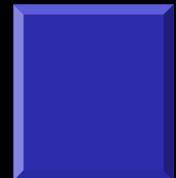
Introduction to Nuclear (Astro) Physics

Krzysztof Starosta
NSCL/MSU

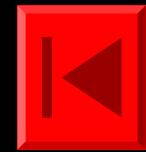
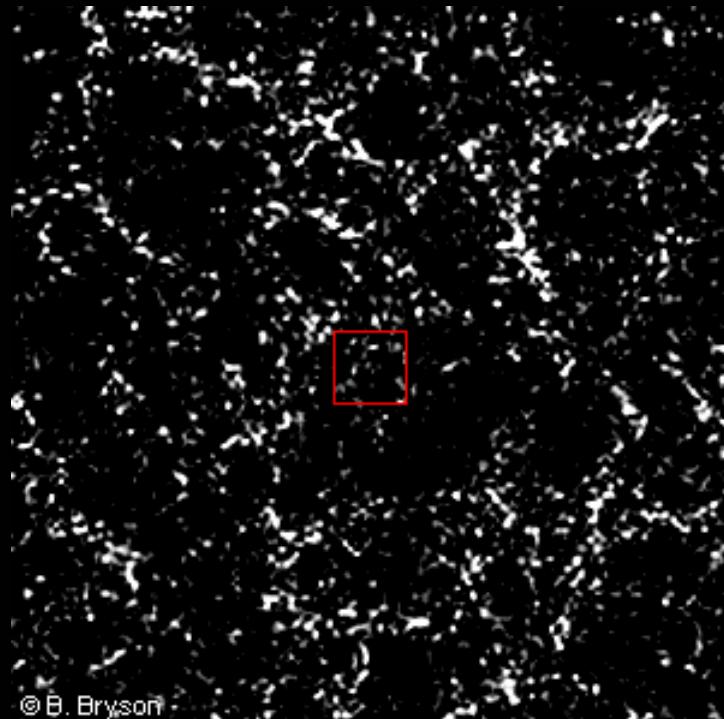
What we know...



- o 10^{26} m ► universe
- o 10^{24} m ► cluster of galaxies
- o 10^{22} m ► milky way
- o 10^{14} m ► solar system/star
- o 10^7 m ► earth
- o 10^0 m ► human beings
- o 10^{-2} m ► insects
- o 10^{-5} m ► cells
- o 10^{-8} m ► DNA
- o 10^{-10} m ► atom
- o 10^{-14} m ► nucleus ►
- o 10^{-15} m ► nucleons ►
- o 10^{-16} m ► quarks/gluons ►

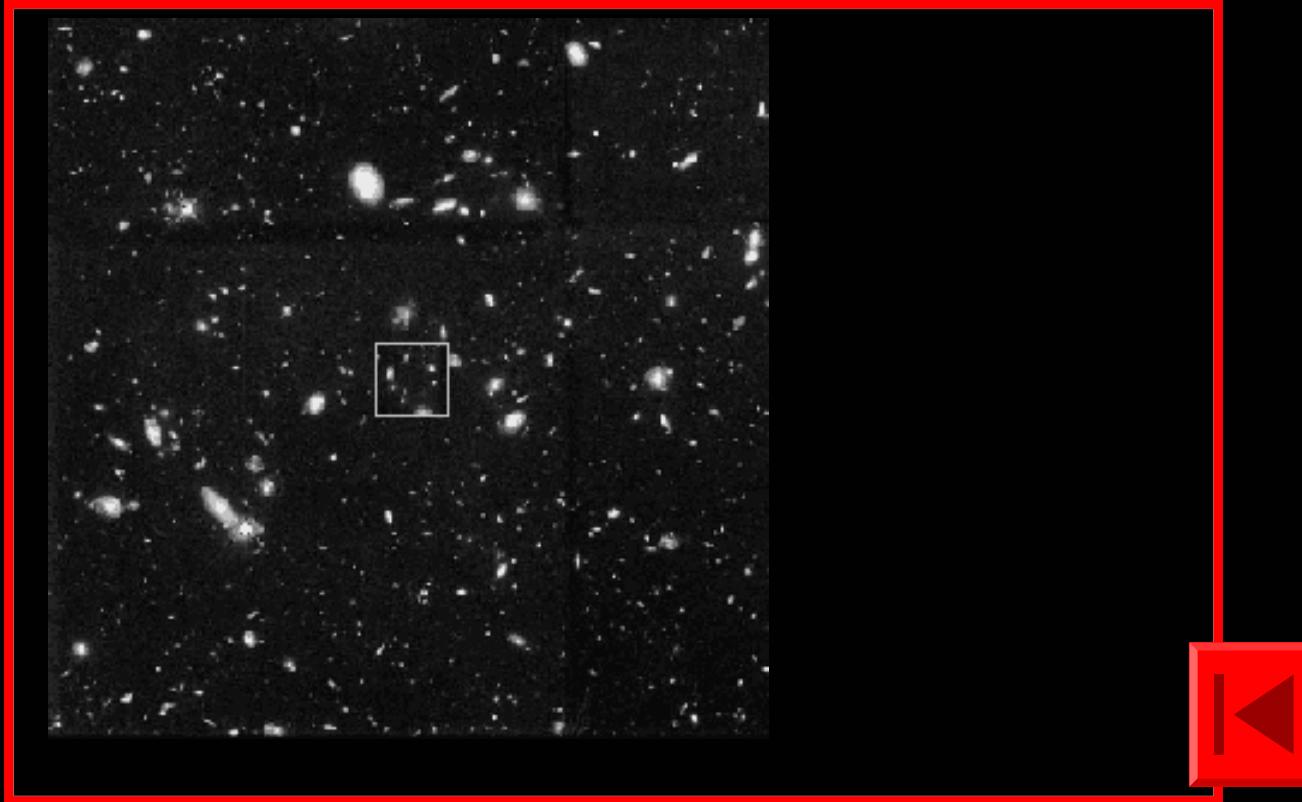


10^{26} m: the universe



The dots are the brightest galaxies

10^{24} m: cluster of galaxies



$\sim 200.000.000$ light years away

10^{22} m: our milky way

Spiral

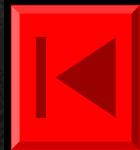


Barred spiral

Elliptical

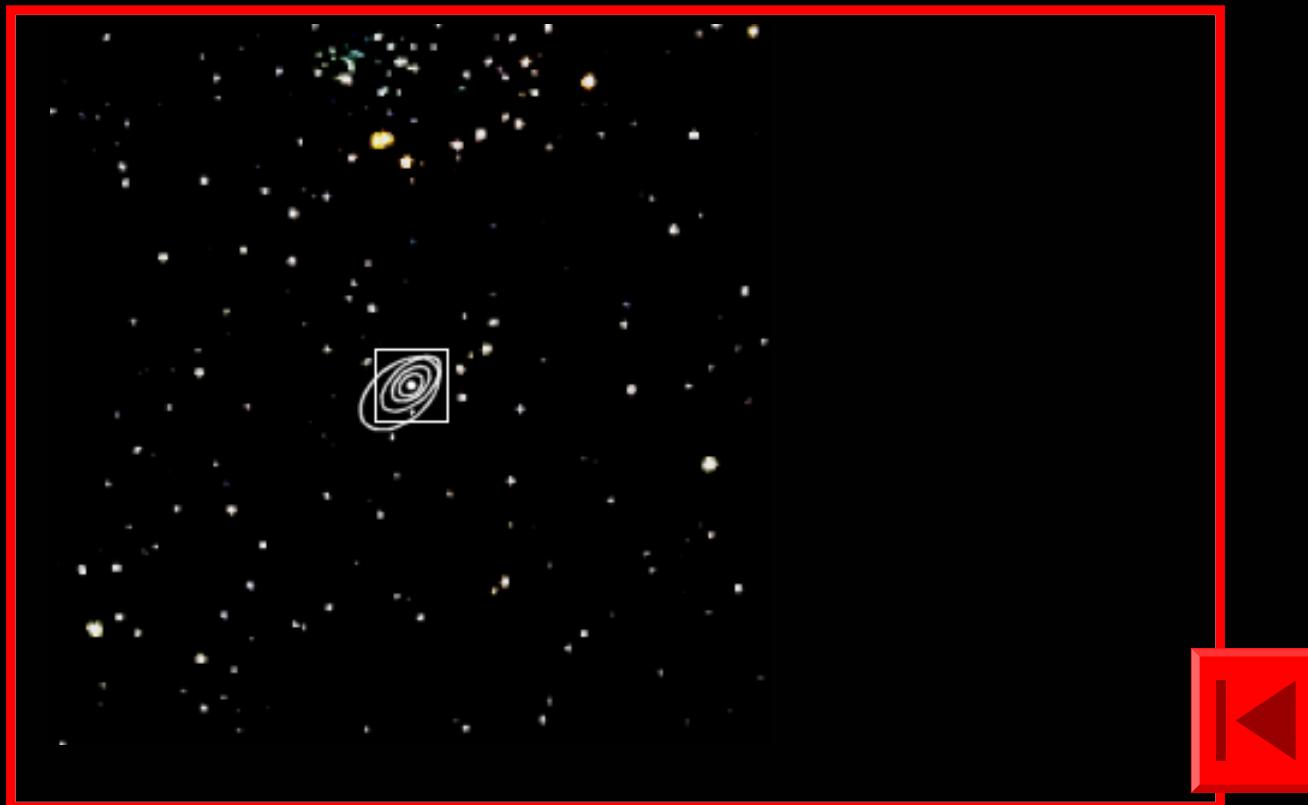


Irregular



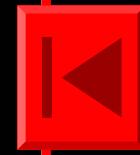
Our milky way is a spiral galaxy

10^{14} m: The solar system/star



The orbits of the nearby planets

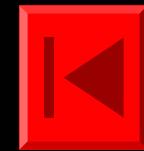
10^7 m: earth



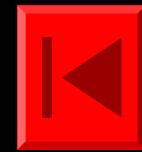
10^0 m: humans



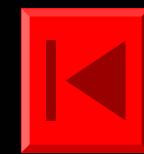
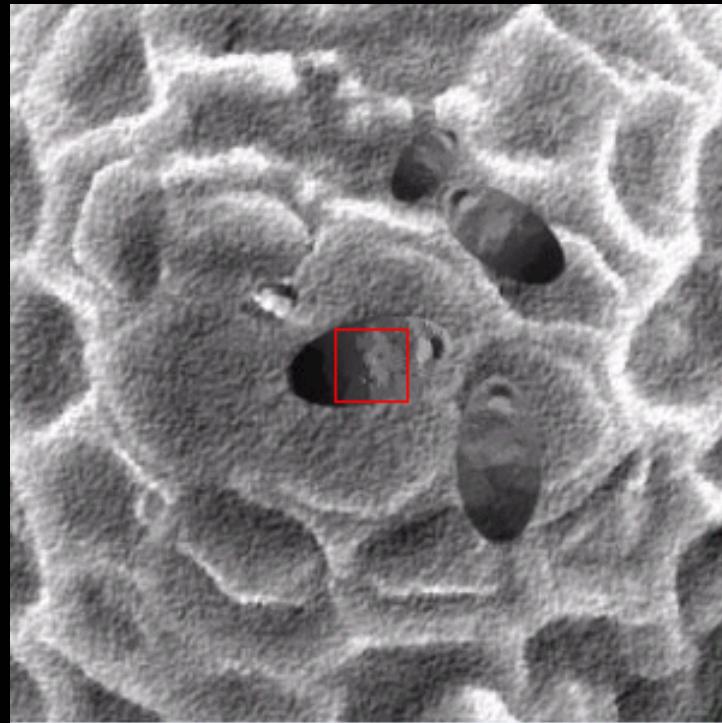
Marie Curie



10^{-2} m insects

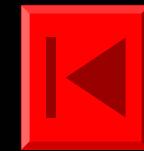
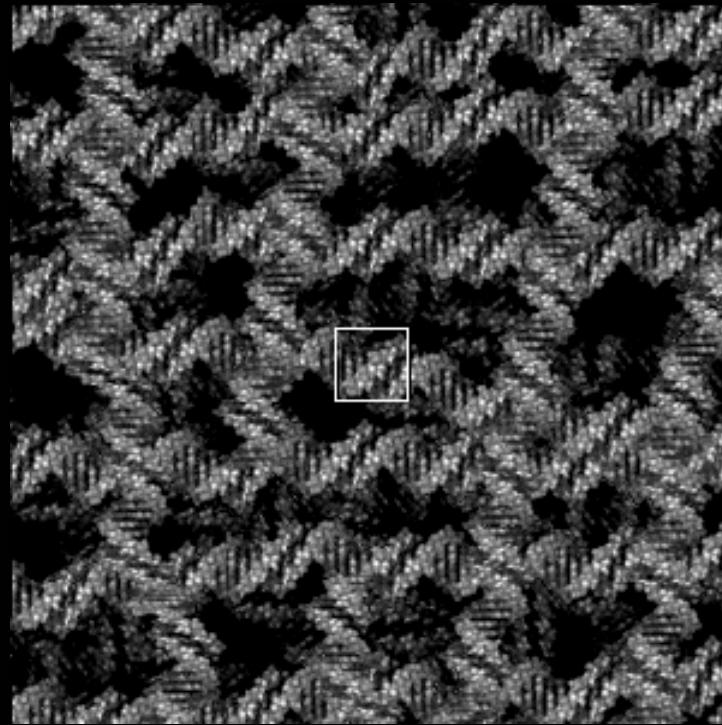


10^{-5} m: a lymphocyte (cell for immune system)

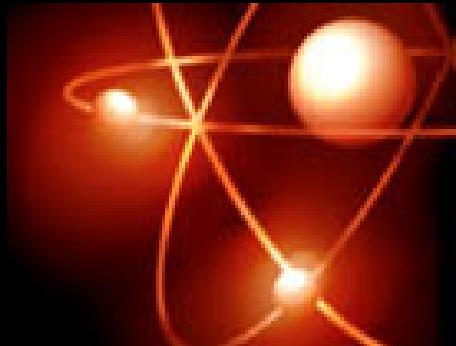


Scale of cellular biology

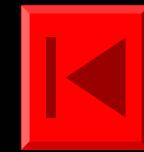
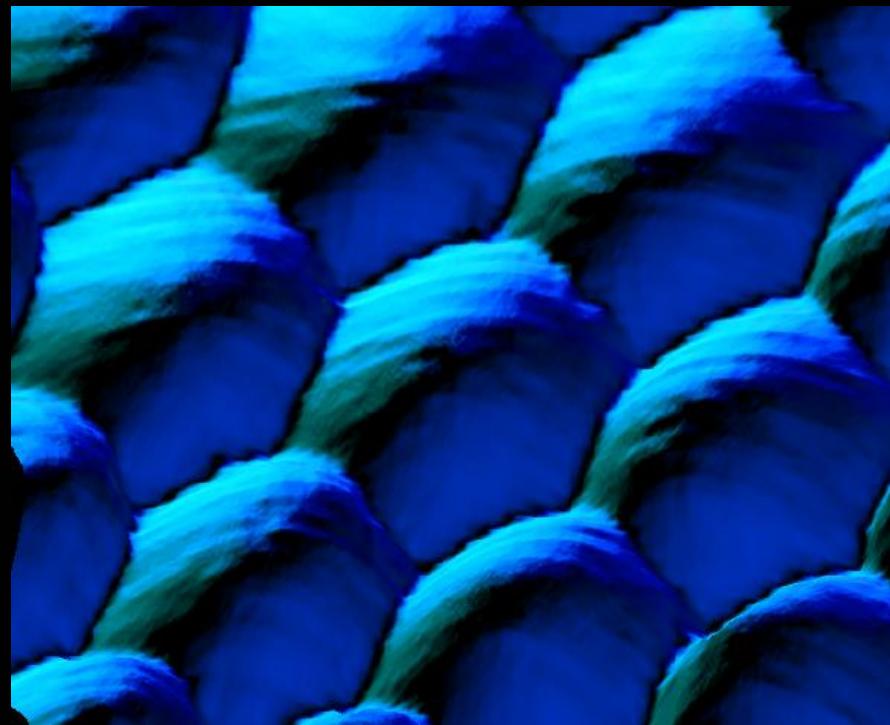
10^{-8} m: DNA



A double helix structure

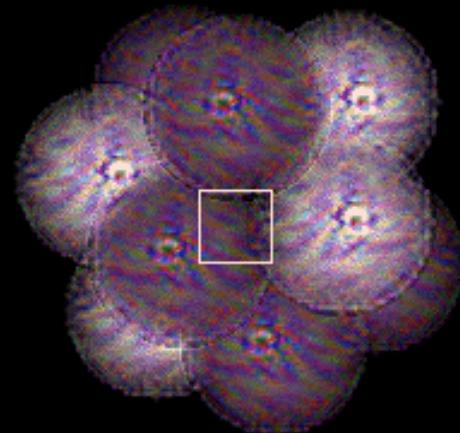


10^{-10} m: atom

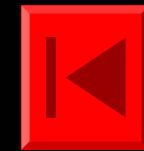


Field Emission Scanning Microscope image
of Platinum surface

10^{-14} m: The nucleus

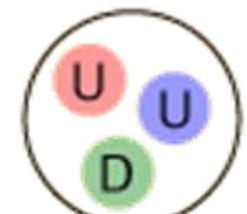


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^{12}C (6 protons and 6 neutrons)

10^{-15}m : nucleons & the particle zoo

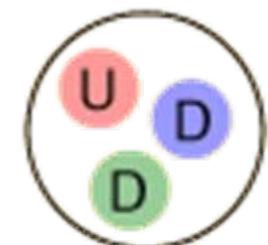


Proton

U = "up" quark $+\frac{2}{3} e$
D = "down" quark $-\frac{1}{3} e$

$$m_p = 1836.15 m_e$$

$$\begin{aligned} \text{Mass} &= 1.6726 \times 10^{-27} \text{ kg} \\ &= 938.27231 \text{ MeV}/c^2 \\ &= 1.00727647 \text{ u} \end{aligned}$$

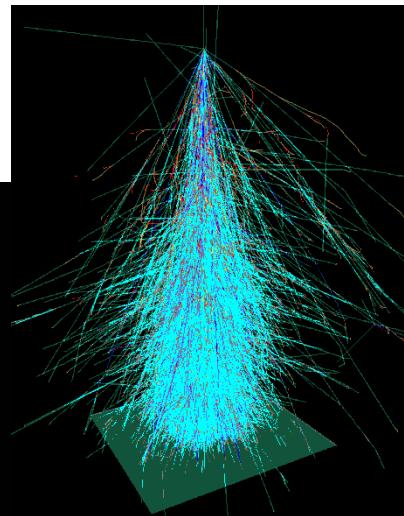


Neutron

U = "up" quark $+\frac{2}{3} e$
D = "down" quark $-\frac{1}{3} e$

$$m_p = 1838.68 m_e$$

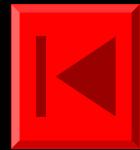
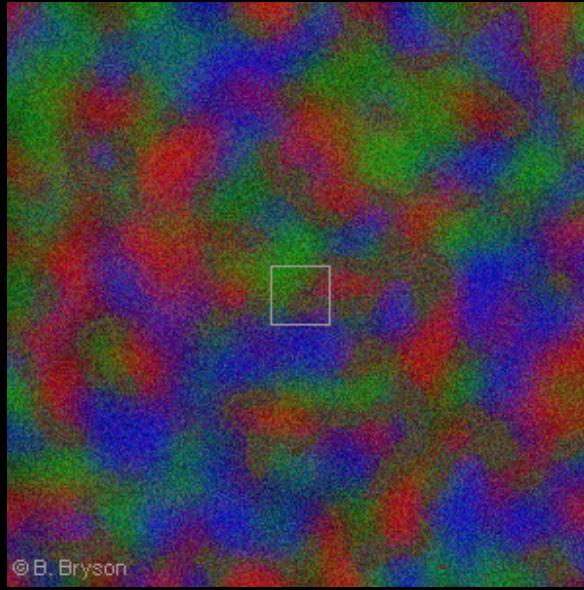
$$\begin{aligned} \text{Mass} &= 1.6749 \times 10^{-27} \text{ kg} \\ &= 939.5656 \text{ MeV}/c^2 \\ &= 1.0086647 \text{ u} \end{aligned}$$



cosmic rays



10^{-16} m: quarks and gluons

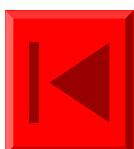
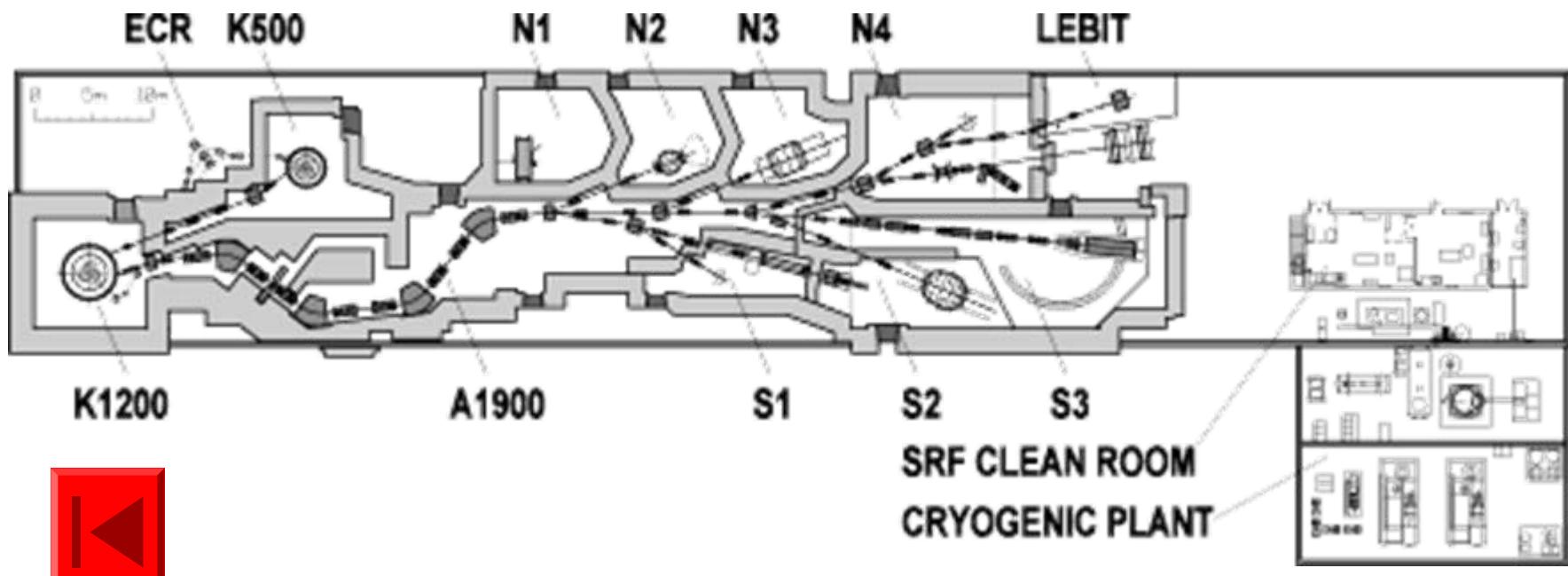


The smallest known building blocks

flavor	Up	Down	Strange	Charm	Bottom	Top
charge	+2/3	-1/3	-1/3	+2/3	-1/3	+2/3
mass (GeV)	0.005	0.01	0.15	1.5	5.0	180



nuclear physics

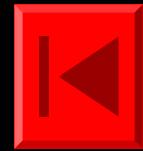




THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY



particle physics





quark-gluon physics

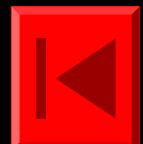
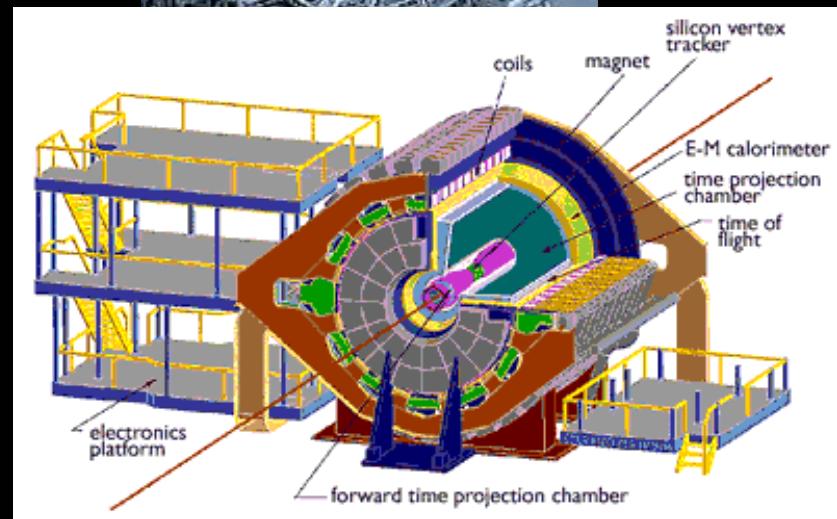
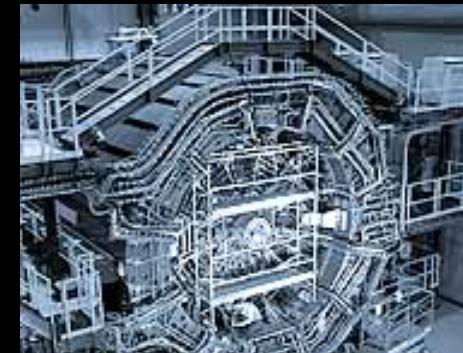
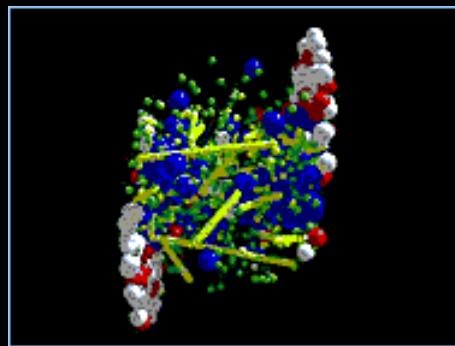


Table of the elements

Periodic Table of the Elements

New Original		Alkali metals		Actinide series		Solid		Liquid		Gas		Synthetic								
1 IA	1 H Hydrogen 1.00794	2 IIA	2 Be Beryllium 9.012182	3 Li Lithium 6.941	4 Be	5 Transition metals	6 Lanthanide series	7 Poor metals	8 Nonmetals	9 Noble gases	10 III A	11 IV A	12 VA	13 VIA	14 VII A	15 VII A	16 VII A	17 VII A	18 VII A	
1 H	2	IIA	2	Li	Be	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Cl
2 Li	3	IIIB	3	Na	Mg	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	S	Ar
3 Na	4	IVB	4	Mg	Magnesium 24.3050	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	P	Ne
4 K	5	V B	5	Ca	Scandium 44.955910	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	S	Ar
5 Rb	6	VIB	6	Sc	Titanium 47.867	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
6 Cs	7	VII B	7	Y	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Br	Ar
7 Fr	8	VIIIB	8	Rb	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
8	9	57 to 71	9	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Ar
9	10	57 to 71	10	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
10	11	57 to 71	11	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
11	12	57 to 71	12	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
12	13	57 to 71	13	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
13	14	57 to 71	14	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
14	15	57 to 71	15	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
15	16	57 to 71	16	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
16	17	57 to 71	17	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
17	18	57 to 71	18	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
18	19	57 to 71	19	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
19	20	57 to 71	20	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
20	21	57 to 71	21	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
21	22	57 to 71	22	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
22	23	57 to 71	23	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
23	24	57 to 71	24	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
24	25	57 to 71	25	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
25	26	57 to 71	26	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
26	27	57 to 71	27	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
27	28	57 to 71	28	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
28	29	57 to 71	29	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
29	30	57 to 71	30	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
30	31	57 to 71	31	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
31	32	57 to 71	32	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
32	33	57 to 71	33	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
33	34	57 to 71	34	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
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35	36	57 to 71	36	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
36	37	57 to 71	37	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
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39	40	57 to 71	40	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
40	41	57 to 71	41	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
41	42	57 to 71	42	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
42	43	57 to 71	43	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
43	44	57 to 71	44	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
44	45	57 to 71	45	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
45	46	57 to 71	46	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
46	47	57 to 71	47	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
47	48	57 to 71	48	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
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50	51	57 to 71	51	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
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52	53	57 to 71	53	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
53	54	57 to 71	54	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
54	55	57 to 71	55	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
55	56	57 to 71	56	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
56	57	57 to 71	57	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
57	58	57 to 71	58	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
58	59	57 to 71	59	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
59	60	57 to 71	60	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
60	61	57 to 71	61	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
61	62	57 to 71	62	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
62	63	57 to 71	63	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
63	64	57 to 71	64	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
64	65	57 to 71	65	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
65	66	57 to 71	66	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
66	67	57 to 71	67	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
67	68	57 to 71	68	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
68	69	57 to 71	69	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
69	70	57 to 71	70	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
70	71	57 to 71	71	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
71	72	57 to 71	72	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
72	73	57 to 71	73	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
73	74	57 to 71	74	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
74	75	57 to 71	75	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
75	76	57 to 71	76	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
76	77	57 to 71	77	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
77	78	57 to 71	78	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
78	79	57 to 71	79	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
79	80	57 to 71	80	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
80	81	57 to 71	81	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
81	82	57 to 71	82	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
82	83	57 to 71	83	Sc	Zr	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Kr
83	84	57 to 71	84	Sc	Zr</															

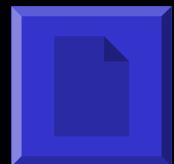


Chart of nuclei

