From Quarks to the Cosmos

Patrick Fox

Fermilab



	1 1.0079			RELATIV	VE ATOMIC N	ASS (1)		(a) 5	Semimetal	Nonme	lete		http	c//www.ktf-	split.hr/per	iodni/en/		2 4.00			
1	H		GRO	OUP IUPAC	G	ROUP CAS		Metal Semimetal Nonmetal Nonmetal													
	HYDROGEN	2_11A		13 11			2 Alk	Alkaline earth metal			17 Halogens element			13 111A 14 IVA 15 VA 16 VIA							
	3 6.941 4 9.0122 ATOMIC NUMBER 5 10.811						Tra	insition metal	s	18 Noble	gas		5 10.811	6 12.011	7 14.007	8 15.999	9 18.998	10 20.			
1	Li	Li Be SYMBOL B						Lanthanide	STAN	DARD STATE	(25 °C; 101 I	(Pa)	В	С	N	0	F	Ne			
	LITHIUM	BERYLLIUM			BORON		/	Ga - liquid Tic - synthetic						CARBON	NITROGEN	OXYGEN	FLUORINE	NEO			
	No	Ma		ELE	MENT NAME				·	1		_	A 1	S:	D C		C1	10 33.			
	SODIUM		3 1118	4 IVB	5 VB	6 VIB	7 VIIB	8	VIIIB -	10	11 18	12 118	ALUMINIUM	SILICON	PHOSPHORUS	SULPHUR	CHLORINE	ARGO			
	19 39.098	20 40.078	21 44.956	22 47.867	23 50.942	24 51.996	25 54.938	26 55.845	27 58.933	28 58.693	29 63.546	30 65.39	31 69.723	32 72.64	33 74.922	34 78.96	35 79.904	36 83			
H	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	K			
	POTASSIUM	CALCIUM	SCANDIUM	TITANIUM	VANADIUM	CHROMIUM	MANGANESE	IRON	COBALT	NICKEL	COPPER	ZINC	GALLIUM	GERMANIUM	ARSENIC	SELENIUM	BROMINE	KRYPT			
	37 85.468	38 87.62	39 88.906	40 91.224	41 92.906	42 95.94	43 (96)	44 101.07	45 102.91	46 106.42	47 107.87	48 112.41	49 114.82	50 118.71	51 121.76	52 127.60	53 126.90	54 13			
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	Ι	X			
	RUBIDIUM	STRONTIUM	YTTRIUM	ZIRCONIUM	NIOBIUM	MOLYBDENUM	TECHNETIUM	RUTHENIUM	RHODIUM	PALLADIUM	SILVER	CADMIUM	INDIUM	TIN	ANTIMONY	TELLURIUM	IODINE	XENO			
	55 132.91	56 137.33	57-71	72 178.49	73 180.95	74 183.84	75 186.21	76 190.23	77 192.22	78 195.08	79 196.97	80 200.59	81 204.38	82 207.2	83 208.98	84 (209)	85 (210)	86 (2			
	Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	TI	Pb	Bi	Po	At	R			
	CAESIUM	BARIUM	Canchamde	HAFNIUM	TANTALUM	TUNGSTEN	RHENIUM	OSMIUM	IRIDIUM	PLATINUM	GOLD	MERCURY	THALLIUM	LEAD	BISMUTH	POLONIUM	ASTATINE	RADO			
	Em	Do	89-103	104 (201)	105 (202)	S		103 (217)	N/14	11 10000	11 (2/2)	II Innllo		II Inn.m							
	FI	па	Actinide	INII		Ng		TUR	IVILU	Uuuu	Uuu	UUUU	$ \rangle$	Ouiq							
-	routerom	roublow	/	Normer or Choice	Doortom	SCABOR GION	Connection	10.33101	METTALKION	OROTATIETOW	CHONONION	ontontonom			1						
			-	LANTHAN	DE		10		10	12					10	Copyright © 19	98-2003 EniG	(eni@ktf-s			
elativ	ve atomic ma reatformer Er	ass is shown	with five	57 138.91	58 140.12	59 140.91	60 144.24	61 (145)	62 150.36	63 151.96	64 157.25	65 158.93	66 162.50	67 164.93	68 167.26	69 168.93	70 173.04	71 17			
nuclides, the value enclosed in brackets indicates the mass number of the knowst-lived				La	Ce	Pr	Nd	1P1m	Sm	Eu	Gđ	TD	Dy	Ho	Er	Tm	YD				
isotope of the element. LANTHANUM CERIUM PRASEODYMUM N However three such elements (Th, Pa, and U)							NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTTERBIUM	LUTET			
do have a characteristic terrestrial isotopic composition, and for these an atomic weight is 89 (227) 90 232.04 91 231.04						92 238.03	93 (237)	94 (244)	95 (243)	95 (243) 96 (247) 97 (2			99 (252)	100 (257)	101 (258)	102 (259)	103 (2				
Ac Th Pa					U	ND	IPm	Am	Cm	IBlk	Cf	IEs	Fin	Md	No	ILI					
Editor; Aditya Vardhan (adivar@netlinx.com) ACTINIUM THORIUM PROTACTINIUM						URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWREN				
		f					http://w			n (on (dou	unload b	tml									





	GROUP		PE	ERI	OD	OIC	TA	BL	E () F	TH	EE		M	EN	TS					
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⁰	L			RELATIV	RELATIVE ATOMIC MASS (1)													Ho			
PER	HYDROCEN	2 110	GROUP IUPAC GROUP CAS					Alkali metal						12 HA 12 BA 17 MA 17 MA 19 MA							
	3 6.941	4 9.0122	ATOMIC	SUMBER 5 10.811			Alkaline earth metal			17 Halogens element			5 10.811	6 12.011	8 15.999	9 18.998	10 20.180				
2	Li	Be	5	SYMBOL B BORON			Lanthanide STAN			DARD STATE (26 °C: 101 kPa)			B	C	N	0	F	Ne			
	LITHIUM	BERYLLIUM						Actinide	Ne	- gas		BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON				
4	11 22.990	12 24.305								Ga - liquid Tc - synthetic			13 26.982	14 28.086	36 15 30.974	16 32.065	17 35.453	18 39.948			
3	Na	Mg			/								Al	Si	P	S	Cl	Ar			
1	SODIUM	MAGNESIUM	3 IIIB	4 IVB	5 / VB	6 /VIB	7 VIIB	8	9	10	11 IB	12 IIB	ALUMINIUM	SILICON	PHOSPHORUS	SULPHUR	CHLORINE	ARGON			
	19 39.098	20 40.078	21 44.956	22 47.867	23 50.942	24 51.996	25 54.938	26 55.845	27 58.933	28 58.693	29 63.546	30 65.39	31 69.723	32 72.64	33 74.922	34 78.96	35 79.904	36 83.80			
- 4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr			
	POTASSIUM	CALCIUM	SCANDIUM	TITANIUM	VANADIUM	CHROMIUM	MANGANESE	IRON	COBALT	NICKEL	COPPER	ZINC	GALLIUM	GERMANIUM	ARSENIC	SELENIUM	BROMINE	KRYPTON			
\leq	37 85.468	38 87.62	39 88.906	40 91.224	41 92.906	42 95.94	43 (98)	44 101.07	45 102.91	46 106.42	47 107.87	48 112.41	49 114.82	50 118.71	51 121.76	52 127.60	53 126.90	54 131.29			
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te		Xe			
	RUBIDIUM	STRONTIUM	YTTRIUM	ZIRCONIUM	NIOBIUM	MOLYBDENUM	TECHNETIUM	RUTHENIUM	RHODIUM	PALLADIUM	SILVER	CADMIUM	INDIUM	TIN	ANTIMONY	TELLURIUM	IODINE	XENON			
ć	55 132.91	50 137.33	57-71	12 178.49	/3 180.95	74 183.84	75 186.21	76 190.23	1/ 192.22	78 195.08	/9 196.97	80 200.59	81 204.38	82 207.2	83 208.98	84 (209)	85 (210)	80 (222)			
	Cs	ва	Lanthanide	HI	Ia	W	Re	Us	Ir	Pt	Au	Hg	11	PD	BI	PO	At	Rn			
	CAESIUM 87 (223)	BARIUM 88 (226)	00.102	HAFNIUM	TANTALUM	TUNGSTEN	RHENIUM	OSMIUM	109 (268)	PLATINUM	GOLD	MERCURY 112 (285)	THALLIUM	LEAD	BISMUTH	POLONIUM	ASTATINE	RADON			
7	Er	Do	89-105 Ac-Lr	10,00		Sa.			TV/IA	II Innno	IT Innnn	II Innllo		II Innon							
	FI	па	Actinide	INII		NE		TUR	IVILU	U	Outur			ાંધાવા							
/	FIGHTCHOM	Totonom	/	LANTHANI	DE	SCADOR GION		THISTICH	METHERION	CHORELOW		Untertailorit			5	Copyright © 19	98-2003 EniG.	(eni@ktf-split.h			
(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001) Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets				57 138.91	58 140.12	59 140.91	60 144.24	61 (145)	62 150.36	63 151.96	64 157.25	65 158.93	66 162.50	67 164.93	68 167.26	69 168.93	70 173.04	71 174.97			
				La	Ce	Pr	Nd	IPm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			
indica	ates the mass n pe of the elemen	umber of the lor 1.	ngest-lived	LANTHANUM	CERIUM	PRASEODYMUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTTERBIUM	LUTETIUM			
do h	ever three such ave a charact	elements (Th, I eristic terrestri	Pa, and U) al isotopic	ACTINIDE	00 000 04	01 004 04	02 000 00	02 (007)	04 1040	05 (010)	06 (017)	07 (017)	00 (054)	00 (050)	100 (057)	101 (050)	102 (050)	102 (000)			
tabul	ated.	unose an albiti	e weight is	(227)	TL	Da	1 238.03	53 (237)	10000	A more	50 (247)	10011-	56 (251)	112 ~	100 (257)	DAT (258)	EX (259)	105 (262)			
				AC	In	Pa	U	Talb	IFUI	(001/A	Cin	TRATIK	CI	ILS	16,100	TATTOI	140	ILI			
Edito	r: Aditya Vardh:	an (adivar@net	llinx.com)	ACTINIUM	THORIUM	PROTACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWRENCIUM			

Electron Proton Neutron







			PF	RI	٥г		ТΔ	RI	F ()E	TH	FF		M	=N1	۲S						
0	GROUP 1 IA 1 1.0079							//	7				http	o;//www.ktf-	split.hr/per	iodni/en/		18 VIIIA 2 4.0026				
PERIOI	HYDROGEN	2 11A	GRO	NUP IUPAC	3 IIIA	ROUP CAS	Me	Metal Semimetal Nonmetal Akali metal Modeline earth metal Met						13 IIIA 14 IVA 15 VA 16 VIA 17 VIIA								
_2	³ 6.941 Li	4 9.0122 Be	Be SYMBOL B				Transition metals			18 Noble	gas (25 °C; 101 k	(Pa)	5 10.811 B	6 12.011 C	7 14.007 N	8 15.999 O	9 18.998 F	10 20.180 Ne				
1	LITHIUM 11 22.990	BERYLLIUM BORON 12 24.305 ELEMENT NAME					1	Actinide Ne - gas Fe - solid Ga - liquid Tit - synthetic						CARBON 14 28.086	NITROGEN 15 30.974	OXYGEN 16 32.065	FLUORINE 17 35.453	NEON 18 39.948				
,	INA sodium 19 39.098	IVIG MAGNESIUM 20 40.078	IVIG MAGNESIUM 3 IIIB 4 IVB 5 VB 6 VIB 20 40.076 21 44.956 22 47.867 23 50.942 24 51.996					VIIB 8 9 10 11 IB 12 5 54 938 26 55 845 27 58 933 28 58 693 29 63 546 30						SILICON 32 72.64	PHOSPHORUS 33 74.922	SULPHUR 34 78.96	CI CHLORINE 35 79.904	Ar ARGON 36 83.80				
-4	K POTASSIUM	Ca	Sc	TI	V	Сг	Mn MANGANESE	Fe	C0 COBALT	NI	Cu	Zn	Gallium	Germanium	AS	Se	BROMINE	KRYPTON				
5	37 85.468 Rb	38 87.62 Sr	39 88.906 Y	40 91.224 Zr	41 92.906 Nb	42 95.94 Mo	43 (96) TC	44 101.07 Ru	45 102.91 Rh	46 106.42 Pd	47 107.87 Ag	48 112.41 Cd	49 114.82 In	50 118.71 Sn	51 121.76 Sb	52 127.60 Te	53 126.90 I	54 131.29 Xe				
6	RUBIDIUM 55 132.91	56 137.33	уттяюм 57-71 La-Lu	ZIRCONIUM 72 178.49	NIOBIUM 73 180.95	74 183.84	75 186.21	RUTHENIUM 76 190.23	RHODIUM 77 192.22	PALLADIUM 78 195.08	SILVER 79 196.97	CADMIUM 80 200.59	INDIUM 81 204.38	TIN 82 207.2 Ph	ANTIMONY 83 208.98	TELLURIUM 84 (209)	IODINE 85 (210)	xenon 86 (222) R n				
	CAESIUM 87 (223)	BARIUM 88 (226)	Lanthanide 89-103	HAFNIUM 104 (261)	TANTALUM 105 (262)	TUNGSTEN 106 (266)	RHENIUM 107 (264)	OSMIUM 108 (277)	IRIDIUM 109 (268)	PLATINUM 110 (281)	GOLD 111 (272)	MERCURY 112 (285)	THALLIUM	LEAD 114 (289)	BISMUTH	POLONIUM	ASTATINE	RADON				
7	Francium	Ra RADIUM	Ac-Lr Actinide	IRII rutherfordium	DUBNIUM	Sg seaborgium	IBh Bohrium	HASSIUM			UUUUU MUINUNUUM	UUD		PUUU								
(1) Pure Rela	Appl. Chem., 7	3, No. 4, 667-6	83 (2001) with_five	57 138.91	DE 58 140.12	59 140.91	60 144.24	61 (145)	62 150.36	63 151.96	64 157.25	65 158.93	66 162.50	67 164.93	68 167.26	Copyright © 19 69 168.93	98-2003 EniG. (70 173.04	eni@ktf-split.hr) 71 174.97				
sign nucl indic isoto How	significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.				Ce	Pr PRASEODYMUM	Nd NEODYMIUM	PIM PROMETHIUM	Sm	EUROPIUM		Tb TERBIUM	Dy DYSPROSIUM	HOLMIUM	Er	Тт тнистим	Yb	LUTETIUM				
do I com tabu	do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.					91 231.04 Pa	92 238.03 U	93 (237) Np	94 (244) PUI	95 (243)	96 (247) Cm	97 (247) Bk	98 (251) Cff	99 (252) ES	100 (257) Fm	101 (258) Md	102 (259) NO	103 (262)				
Edit Fo	or: Aditya Vardh: r more in	an (adivar@net formatio	tinx.com) in and do	ACTINIUM	THORIUM	PROTACTINIUM	uranium	NEPTUNIUM	PLUTONIUM	AMERICIUM	curium wnload.h	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWRENCIUM				
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 $W^{\pm} Z^0$

gluon









Finally arrive at the **Standard Model**

Elementary Particles





How do we find all these particles?









How do we find all these particles?



Experimental physicist in the lab







The TeVatron







Discovered the top quark, 1995

The TeVatron I work here







Discovered the top quark, 1995

The TeVatron



- •4 miles around
- •Collides protons and anti-protons
- •World's highest energy machine, ~2 TeV
- •Two experiments: DO, CDF
- Superconducting magnets
- •Running brilliantly, delivering new results all
- the time e.g. $\Omega_b B_s$

Top quark (~170 x proton mass!)



 $E = mc^2$

The energy of the colliding proton and antiproton is transformed into the masses of the much more massive top and antitop quarks.





CERN

Discovered the W and Z, 1983







Large Hadron Collider (LHC)

Largest, most complicated science experiment ever attempted. 7 x the energy of the Tevatron (14 TeV)

Large Hadron Collider (LHC)







Large Hadron Collider (LHC)

- •17 miles around, cooled to 1.9K
- 120 ton of liquid He (1% annual production)
- •Collides protons and protons
- •Very high energy (14 TeV)
- •Equivalent to 737 at landing (60kg TNT)
- •40M collisions/sec -> record 200/sec =2MB/s







3000-4000 people

LHC pyjama party: 1am Sep 10, 2008



LHC will start-up again Oct, 09

The **BIG** questions

- •What gives the particles their mass?
- •Why 3 generations?
- •Why is gravity so weak?
- •Why 3 forces, are they really the same?
- •Why do they have the masses they have?
- •Why is there matter and no antimatter?
- •What makes up the Universe?

•…?

The hunt for the Higgs boson

Higgs is responsible for mass of all the standard model particles

Still not seen

Higgs cocktail party analogy:







The TeVatron is getting close....



The SM (with Higgs) is not complete

Observations of galaxies tell us





The SM (with Higgs) is not complete

Ś Observations of Ś galaxies tell us dark matter 73% DARK ENERGY 23% DARK MATTER luminous matter 3.6% INTERGALACTIC GAS STARS, ETC.

Standard Model

The SM (with Higgs) is not complete

Observations of

Gal Session NA: AAPT Plenary – Dark Matter in the Laboratory

Location: H-Grand Ballroom EF Sponsor: AAPT Date: Monday, Feb. 16 Time: 11:30 a.m.–12:30 p.m. Presider: David Cook

Joseph D. Lykken, Fermilab, 1707 E. Thomas Rd., Wheaton, IL 60187; lykken@fnal.gov

Joseph D. Lykken

CTIC GAS

Most of the universe is dark matter, whose composition is entirely unknown and may involve new forces or principles of nature. Using ultra-sensitive detectors deep underground, physicists are attempting to detect dark matter particles streaming in from space. At the Large Hadron Collider, physicists hope to manufacture large numbers of dark matter particles and study their properties in the laboratory. I will describe these efforts and how impending discoveries may change our fundamental understanding of physics and the universe.

?

Standard Model

Other reasons to believe in new physics e.g.

Extra dimensions of space
Second copy of SM - supersymmetry

Both predict new particles and Dark Matter possibilities

Colliders and Cosmos probing the same physics!

Extra dimensions of space, curled up very small May be able to see them at TeVatron/ LHC! Supersymmetry is a new symmetry of nature, only noticeable at short distances. New particles made in collisions







Keep your eye on the headlines!

•Very exciting times ahead •Expect important discoveries impacting microscopic and macroscopic physics Many long standing mysteries may be solved:

Origin of mass, source of most of universe's matter, why not antimatter, unification of forces....

The **BIG** questions

- •What gives the particles their mass?
- •Why 3 generations?
- •Why is gravity so weak?
- •Why 3 forces, are they really the same?
- •Why do they have the masses they have?
- •Why is there matter and no antimatter?
- •What makes up the Universe?

•…?