Ancient Greeks believed that there were four elements:

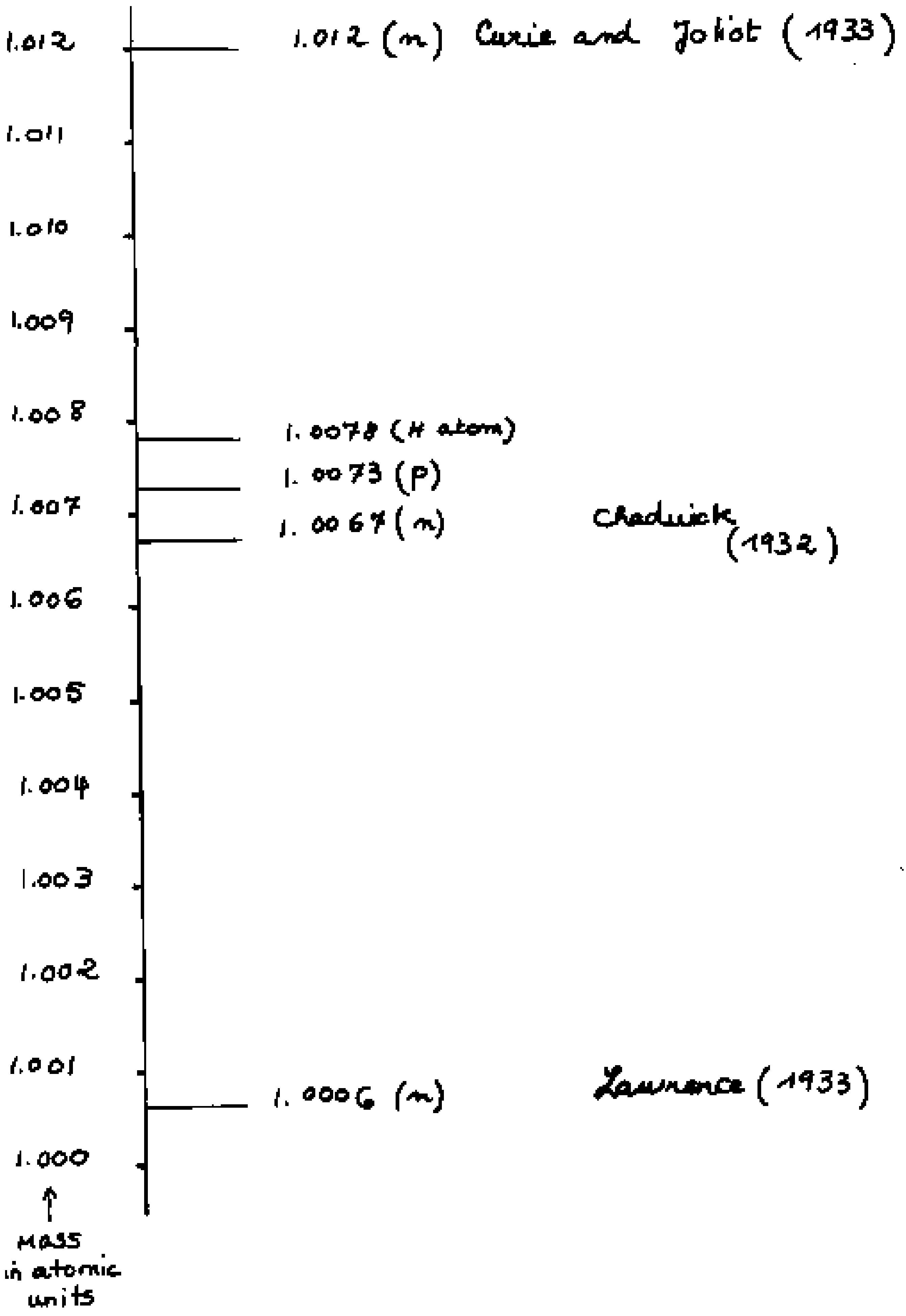
Air, Fire, Earth, Water

A F E W

PERIODIC TABLE OF THE ELEMENTS

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosph. 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge German. 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.94	43 Tc Technet. (97.907215)	44 Ru Ruthen. 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57–71 Lantha-nides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (208.982415)	85 At Astatine (209.987131)	86 Rn Radon (222.017570)
87 Fr Francium (223.019731)	88 Ra Radium (226.025402)	89–103 Actinides	104 Rf Rutherford. (261.1089)	105 Db Dubnium (262.1144)	106 Sg Seaborg. (263.1186)	107 Bh Bohrium (262.1231)	108 Hs Hassium (265.1306)	109 Mt Meitner. (266.1378)	110 (269, 273)	111 (272)	112 (277)		114 (289)		116 (289)		118 (293)

Lanthanide series	57 La Lanthan. 138.9055	58 Ce Cerium 140.116	59 Pr Praseodym. 140.90765	60 Nd Neodym. 144.24	61 Pm Prometh. (144.912745)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolin. 157.25	65 Tb Terbium 158.92534	66 Dy Dyspros. 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide series	89 Ac Actinium (227.027747)	90 Th Thorium 232.0381	91 Pa Protactin. 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237.048166)	94 Pu Plutonium (244.064197)	95 Am Americ. (243.061372)	96 Cm Curium (247.070346)	97 Bk Berkelium (247.070298)	98 Cf Californ. (251.079579)	99 Es Einstein. (252.08297)	100 Fm Fermium (257.095096)	101 Md Mendelev. (258.098427)	102 No Nobelium (259.1011)	103 Lr Lawrenc. (262.1098)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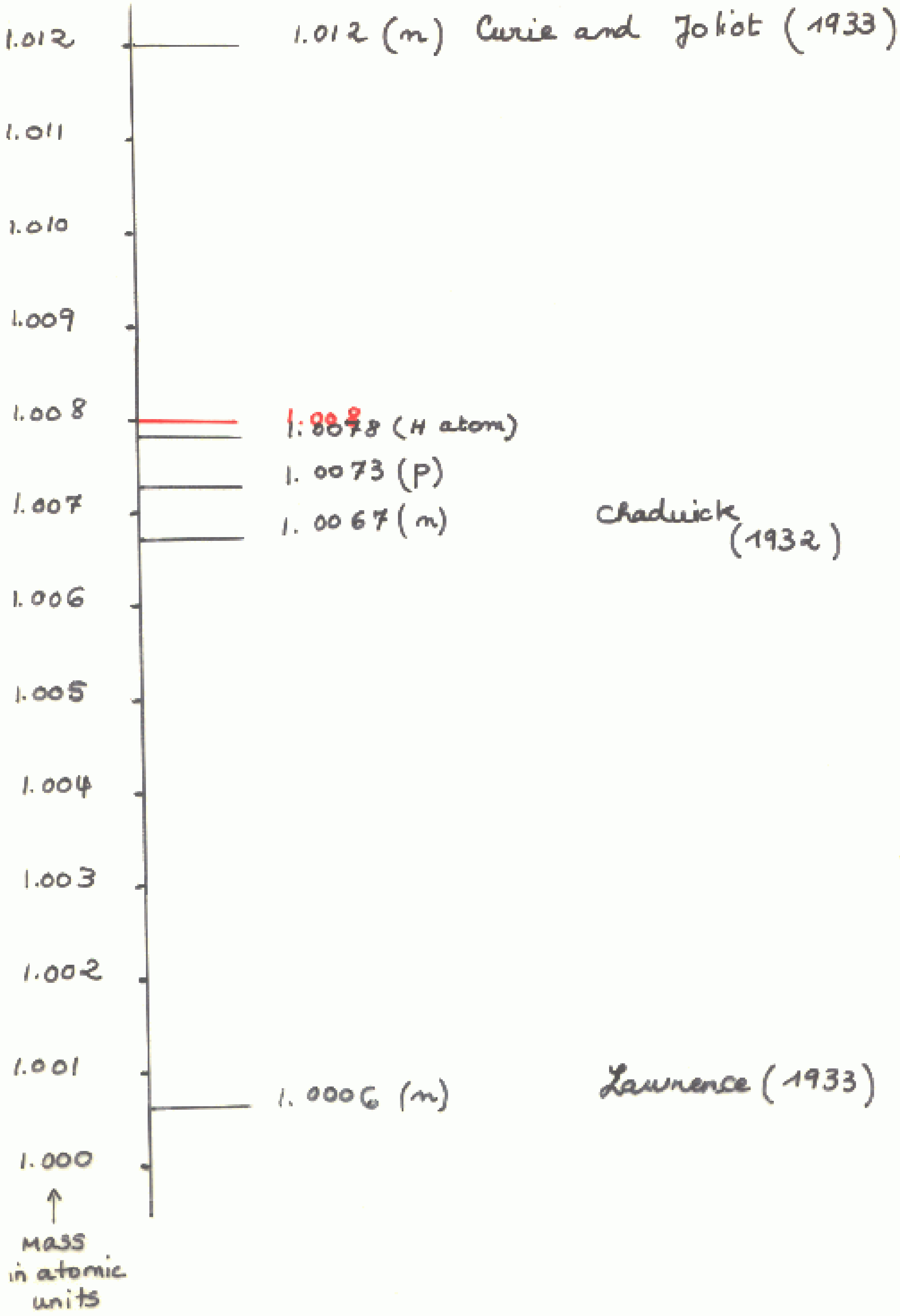
MASS in atomic units
1.012 (n) Curie and Joliot (1933)
1.0078 (H atom)
1.0073 (p)
1.0067 (n)
Chadwick (1932)
1.0006 (n)
Lawrence (1933)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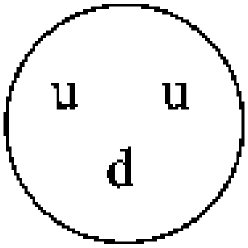

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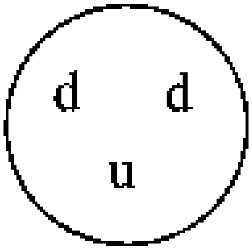

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Table I

The Three Generations of Elementary Fermions

$$i = 3 \quad \begin{pmatrix} \mathrm{t}\,(1.743 \pm 0.05) \times 10^{5} & & \tau\,(1.777 \times 10^{3}) \\ \mathrm{b}\,(4 - 4.3) \times 10^{3} & & \nu_\tau\,(<2.8 \times 10^{-6}) \end{pmatrix}$$

$$i = 2 \quad \begin{pmatrix} \mathrm{c}\,(1.15 - 1.35) \times 10^{3} & & \mu\,(105.67) \\ s\,(75 - 170) & & \nu_\mu\,(<2.8 \times 10^{-6}) \end{pmatrix}$$

$$i = 1 \quad \begin{pmatrix} u\,(1 - 5) & (\ d/u = 0.20\text{-}0.70\ ) & e\,(0.51) \\ d\,(3 - 9) & & \nu_e\,(<2.8 \times 10^{-6}) \end{pmatrix}$$

The values of the masses (in MeV) are taken from reference (2), pp. 23 and 26, except the mass limits for the neutrinos. For ν_e we quote the limits recently reported by the Mainz and Troitsk collaborations (3). Because of the small upper limits for the mass differences *within* the neutrino triplet of mass eigenstates, deduced from neutrino-oscillation experiments (see below), the mass limits for ν_μ and ν_τ can be taken as the same as that for ν_e.

For the lightest quarks, *u*, *d*, *s*, so-called 'current masses' are quoted; they are not directly measurable but derived from the SM. The masses of complex particles containing these quarks (for example, nucleons) then are equal to the equivalent of the quarks' potential and kinetic energies. The masses of the heavier quarks are essentially directly measured.

Table II

Elementary Interactions of the Elementary Fermions

Interactions	**Relative Strength**	**Leptons**		**Quarks**
		ν_l	e_l	u_l , d_l
Strong	1			X
Electro-magnetic	10^{-2}		X	X
Weak	10^{-5}	X	X	X
Gravitational	10^{-39}	X	X	X

The approximate relative strengths of the interactions, 'hierarchically' arranged, are found to be independent of the generation number (universality). Because the interactions vary with energy they are characterized here at a scale of ~ 1 GeV.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} 0.9742 \text{ to } 0.9575 & 0.219 \text{ to } 0.226 & 0.002 \text{ to } 0.005 \\ 0.210 \text{ to } 0.225 & 0.9734 \text{ to } 0.9749 & 0.037 \text{ to } 0.043 \\ 0.004 \text{ to } 0.014 & 0.035 \text{ to } 0.043 & 0.9990 \text{ to } 0.9993 \end{pmatrix}$$

Table III

The Mean Values of the Absolute C-K-M Matrix Elements $\left|\overline{V_{u_i d_j}}\right|$

$\lvert i-j \rvert$	0			1				2	
i	1	2	3	1	2	2	3	1	3
j	1	2	3	2	1	3	2	3	1
	0.9750	0.9742	0.9992	0.222	0.223	0.040	0.039	0.004	0.009

- **Rule 1:** Corresponding elementary fermions of different generations are associated with the same elementary interactions.
- **Rule 2:** Within each generation, there is a correlation between the mass of an elementary fermion and the relative strength of its dominant interaction (elaborated further below).
- **Rule 3:** Besides its dominant interaction, each elementary fermion possesses *all* weaker ones.
- **Rule 4:** As the generation number i increases, the mass differences m (u_i) – m (d_i) and m (e_i) – m (v_i) also increase.
- **Rule 5:** The matrix elements of the C-K-M matrix decrease as $|i\text{-}j|$ increases from 0 to 2, with $|\overline{V_{u_i d_j}}| \approx |\overline{V_{u_j d_i}}|$.

Black – Deduced from Known Regularities and Rules

Red – Deduced from Finite Sources Shapes

- We learned that elementary interactions are connected with appropriate elementary fermions from each generation, and raised the question whether this should be extended to the gravitational interaction.
- The happenstance of the chronological order of discovery of elementary fermions, correlated with the increase of available energies with time, led to their assignments to the different generations in hierarchical order of their masses. We have made it plausible that this is to be expected if a 'hidden' physical property, the source-shape, changes systematically from the first to the third generation and that this may be connected with the three-dimensionality of space.
- While many successes of the SM were not discussed here, and will usually not be affected by our considerations, small deviations from its predictions may result from some of the suggested modifications.
- The large increases in the mass difference between u_i and d_i with i indicate that the postulated hyper-strong interaction of the u_i would have more impact on the self-interaction, as the shapes become more singular. This would be so, if it is mainly a *high*-energy interaction, while the effective QCD self-interaction is a comparatively *low*-energy interaction.
- If the hyper-strong interaction exists, one would expect that the cross sections for producing e.g. $c + \bar{c}$ and $t + \bar{t}$ well above their thresholds would deviate from QCD predictions.

- A hyper-strong force connected only with the u_i, but not the d_i, might be responsible for breaking the chiral symmetries incorporated into the SM. (This conclusion has something in common with the suggestion by Bardeen, Hill and Lindner of a dynamical symmetry breaking of the SM by a $(t\bar{t})$ condensate, with the large mass of t ascribed to a new interaction, called topcolor. The Higgs boson is then considered to be a $(\bar{t}t)$ compound, with a mass, estimated by Chivukula at <500 Gev).
- If elementary fermions with only gravitational interactions should exist, they might be a new link between gravitational theory and quantum mechanics.
- Though the variation of the C-K-M matrix elements has been ascribed to a variation in the weak mixing of quarks, finite source-shapes may permit an alternative explanation: Direct flavor-changing, charge-current weak interactions (e.g., s→u) of the same universal strength as those that do not change flavor might exist, with the size of the matrix elements governed by the amount of overlap of the different source-shapes.