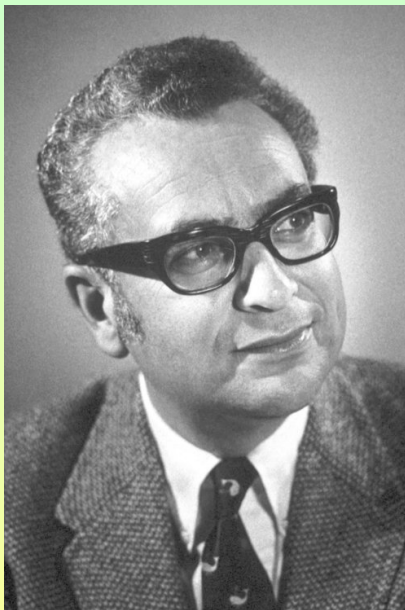# REMEMBERING MURRAY GELL-MANN
Physics, Complexity and Personal Interactions

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M. Gell-Mann (1929, Manhattan−2018, Santa Fe)

Introduction

Born in a family of Jewish immigrants, originally from the Ukraine. Original name Hell-Mann, later Russified to Gell-Mann:

Ambiguity with the letter Γ in Cyrillic script which stands for H in Ukranian and G in Russian.

W-boson vs. X-boson: Mayan word Ux meaning soul: soul of weak interactions.

Roy

Bose

Jackiw

Pipes

Polymath: Interests covered

- Particle Physics*
- Evolution of languages (names)*
- Archeology
- Natural history
- Complex adaptive systems*
- Bio-cultural evolution of mankind
- Process of learning

Education

- Columbia Grammar & Preparatory School
- Yale (AB, 1948)
- MIT (Ph.D, 1951, supervisor V. Weisskopf)

Academic Career

- Princeton Inst. for Advanced Study (Postdoc 1951-2)
- U. Illinois, Urbana-Champagne (Asst. Prof. 1952-4)
- U. Chicago (Assoc. Prof. 1954-5)
- Caltech (Robert Andrews Millikan Professor 1955-93)
- Santa Fe Institute (Cofounder & Distinguished Fellow, Santa Fe Institute 1984-2018)
- John D. Catherine T. MaCarthur Foundation (Director 1979-2018)

Major Honors

- Dannie Heinemann Prize in Mathematical Physics (1959)
- Ernest O. Lawrence Memorial Award (1966)
- Nobel Prize (1969) in Physics
- Ettore Majorana "Science for Peace" Prize (1989)
- Albert Einstein Medal (2005)
- Fellow & Foreign Fellow of numerous national Academies & Societies (e.g. the Royal Society)

Particle Physics Contributions

- (1952-3) Early well-cited work on Dispersion Relations (with Goldberger, Kroll, Low) in the complex plane of momenta of colliding particles (p, q):
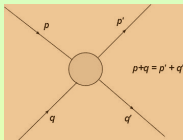
- (1954) Renormalization group (with Low): Coupling strength g (e.g., e in QED) becomes $g(\mu)$ with energy scale μ on account of quantum loops.
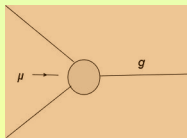
- Eqn. in modern notation

$$\frac{\partial}{\partial \mu} g(\mu) = \beta(g)$$

Calculate RHS order by order in perturbation theory.

Gell-Mann-Nishijima formula

Strangeness (S) and Hypercharge (Y):

$$Q = I_3 + \frac{1}{2} \underbrace{(B + S)}_{\text{hypercharge } Y} .$$

Strange particles (hyperons $\Lambda, \Sigma^{\pm,0}$ and K mesons) discovered in cosmic rays. Success of the formula:

$$\Sigma^+ : Q = 1, I_3 = 1, B = 1, S = 1,$$
$$K^0 : Q = 1, I_3 = -\frac{1}{2}, B = 0, S = -1,$$
$$u\text{-quark} : Q = +\frac{2}{3}, I_3 = \frac{1}{2}, B = \frac{1}{3}, S = 0.$$

V−A theory

Weak interactions (radioactivity and stellar reactions that cause stars to shine).

Fermi's theory

$$H_I = \frac{G_F}{\sqrt{2}} J_w^\dagger J_w.$$

J_W supposedly like vector current J_{EM} ($\bar{\psi}\gamma\psi$).

But the decay $B^{12} \to C^{12} e^- \bar{\nu}$ occurs with B^{12} and C^{12} both carrying spin 1. Vector current cannot take $|\text{spin}1\rangle$ to $|\text{spin}1\rangle$. Need other currents: scalar, pseudoscalar, axial vector, tensor?

Sudarshan and Marshak (1957) proposed vector−axial vector i.e., V−A from a beautiful symmetry argument. Unfortunately, this appeared only in a conf. proc. (Padua-Venice 1957).

V−A theory (Contd.)

Feynman and Gell-Mann also proposed V−A in a Phys. Rev. paper (1958) along with other properties of the V-part.

Initial disagreement with polarized He^6 β-decay expt. of Rustad and Ruby, favoring scalar and pseudoscalar currents. 7th Rochester conf.: Gell-Mann's declaration "That expt. has got to be wrong since the V−A theory is so beautiful". Vindicated by later expts.

Credit initially and unfairly snatched by Feynman and Gell-Mann. Later justice has been restored. Feynman's public acknowledgement: "V−A theory was proposed by Sudarshan and Marshak, but published by Feynman and Gell-Mann."

The Eightfold Way

Inspired by Buddha's ashtamarga: (1) right view, (2) right intention, (3) right speech, (4) right action, (5) right livelihood, (6) right effort, (7) right concentration, (8) right mindfulness $\rightarrow$ lead to Arhat (perfection).
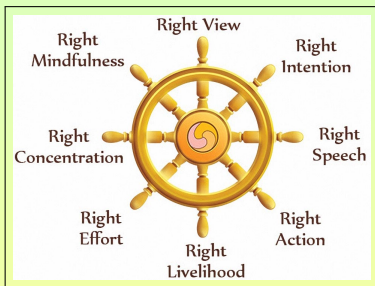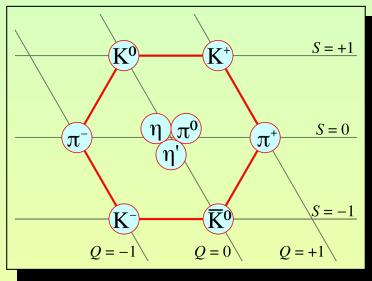

Gell-Mann and independently Y. Neeman of Israel proposed it in 1961 as a classification scheme for mesons (spin zero hadrons) and baryons (spin half hadrons) organized in groups of eight (octet) in the Q-S plane. Octet is a representation of the symmetry group SU(3).

The Eightfold Way (Contd.)
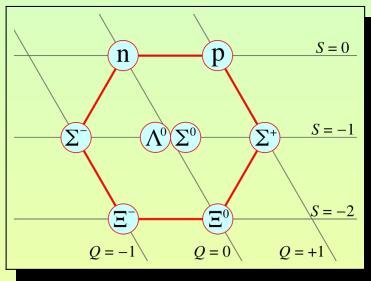

Baryon Octet

Meson Octet

Also, other multiplets. Led to a revolution in the study of hadrons and to Gell-Mann's 1969 Nobel prize.
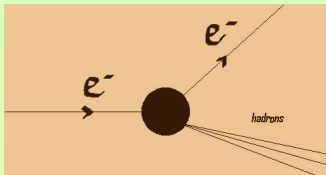
Quarks

Octet is a higher dimensional representation of SU(3). Fundamentals are triplet (3) and antitriplet ($\bar{3}$). In 1964, Gell-Mann and independently Zweig, proposed the existence of fractionally charged objects occurring in these on the $I_3 - Y$ plane.

But they are not seen directly. Gell-Mann's proposed name "quarks" came from "Three quarks for Master Mark" (Finnegan's Wake, James Joyce). He proposed them as fictitious but necessary fundamental constituents of all hadrons.
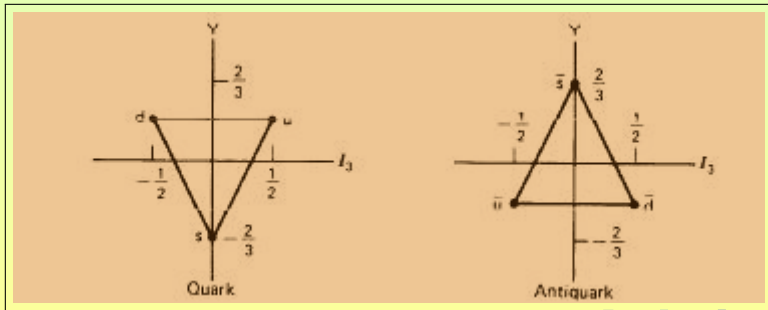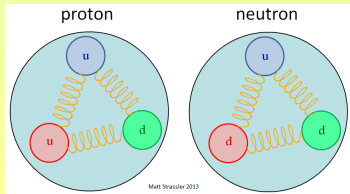
Quarks (Contd.)

1967-8: SLAC expts. scattered electrons from nucleons (protons and neutrons) at high momentum transfer (several 10^9eV) to demonstrate their existence!


Analogy: 3 coins inside a closed transparent plastic ball. Demonstrated constituents of a nucleon (quarks, sea of $q\bar{q}$ pairs and adhesive bosons called gluons) from deep inelastic eN scattering.

Quantum Chromodynamics (QCD)

Quarks and gluons: permanently confined. But ordinary photonlike gluons don't confine! Need a new quantum number called color and a new exact symmetry group color SU(3). A quark (antiquark) is in a color triplet (antitriplet) and gluons (like $q\bar{q}$) lie in a color octet. Theory proposed by Fritzsch, Gell-Mann and Lleutwyler in 1973. Has withstood all experimental tests till today. Acknowledged as the theory of strong interactions.

Interactions of QCD:
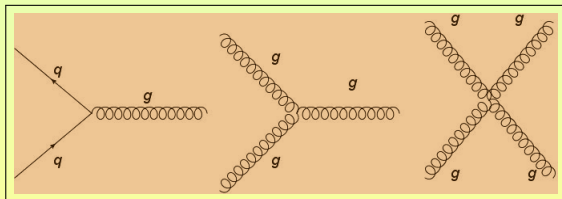
Non-particle Physics Interests & Activities

The *Simple* and the *Complex*

quark   jaguar

"The world of the quark has everything to do
with a jaguar circling in the night."

-Arthur Sze,
-Chinese-American poet.

'Simplicity' comes from the Greek "once folded", 'complexity' comes from "braided together": both 'plic-' for fold & 'plex-' for braid come from the Indo-European word "pleck".

Quark:a simple unit of matter

Jaguar: a complex adaptive system avoiding a clear analytical description.

What is the relation between them? Major topic of investigation at the Santa Fe Institute.

Non-particle Physics Interests & Activities (Contd.)

A complex adaptive system acquires information about its interactions with its environment, identifying regularities which it condenses into a kind of "schema" or model. It is this schema which relates to the fundamental laws.
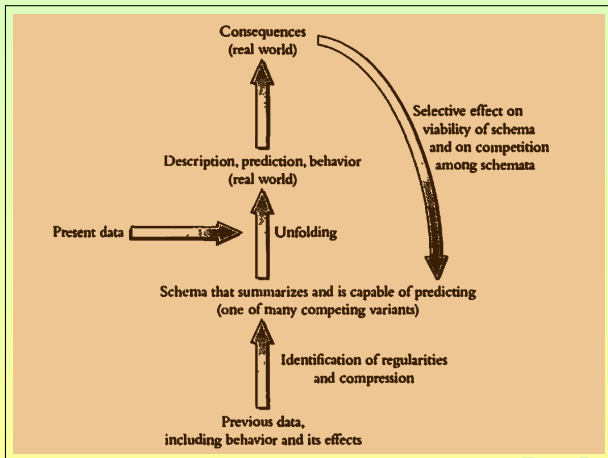
Non-particle Physics Interests & Activities (Contd.)

That is how a running dog catching a Frisbee in its mouth gets related to Newton's laws.

Non-particle Physics Interests & Activities (Contd.)

The same goes for a crouching black jaguar about to jump on its prey.

Non-particle Physics Interests & Activities (Contd.)

Gell-Mann had applied this analysis to problems as diverse as deterministic chaos in money markets, child learning a language and bacteria developing drug resistance plus the Schrödinger's Cat Paradox as well as the Many Worlds interpretation of Quantum Mechanics. These were his main contributions in the area of complexity.

FINAL WORD

(The last sentence of "The Q and the J"). It sums up Gell-Mann's vision of the most desirable world: " A sustainable world is one in which humanity as a whole and the rest of nature operate as a complex adaptive system to a much greater degree than they do now."