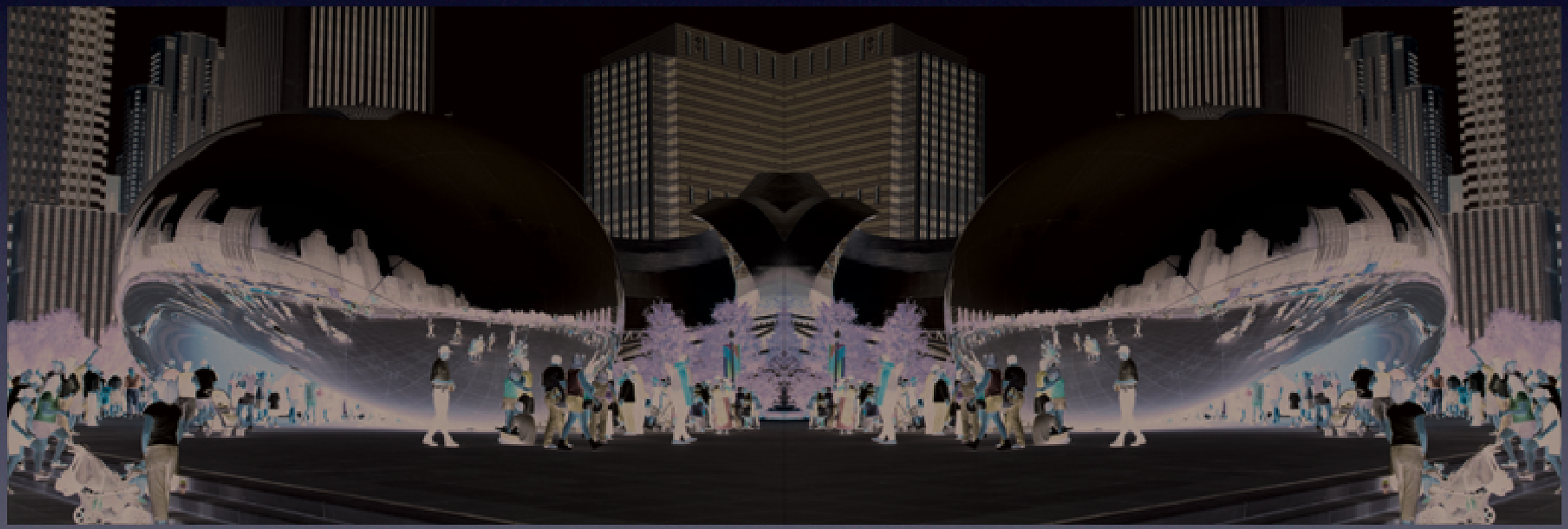
The Nature of Science

Chris Quigg
Fermi National Accelerator Laboratory



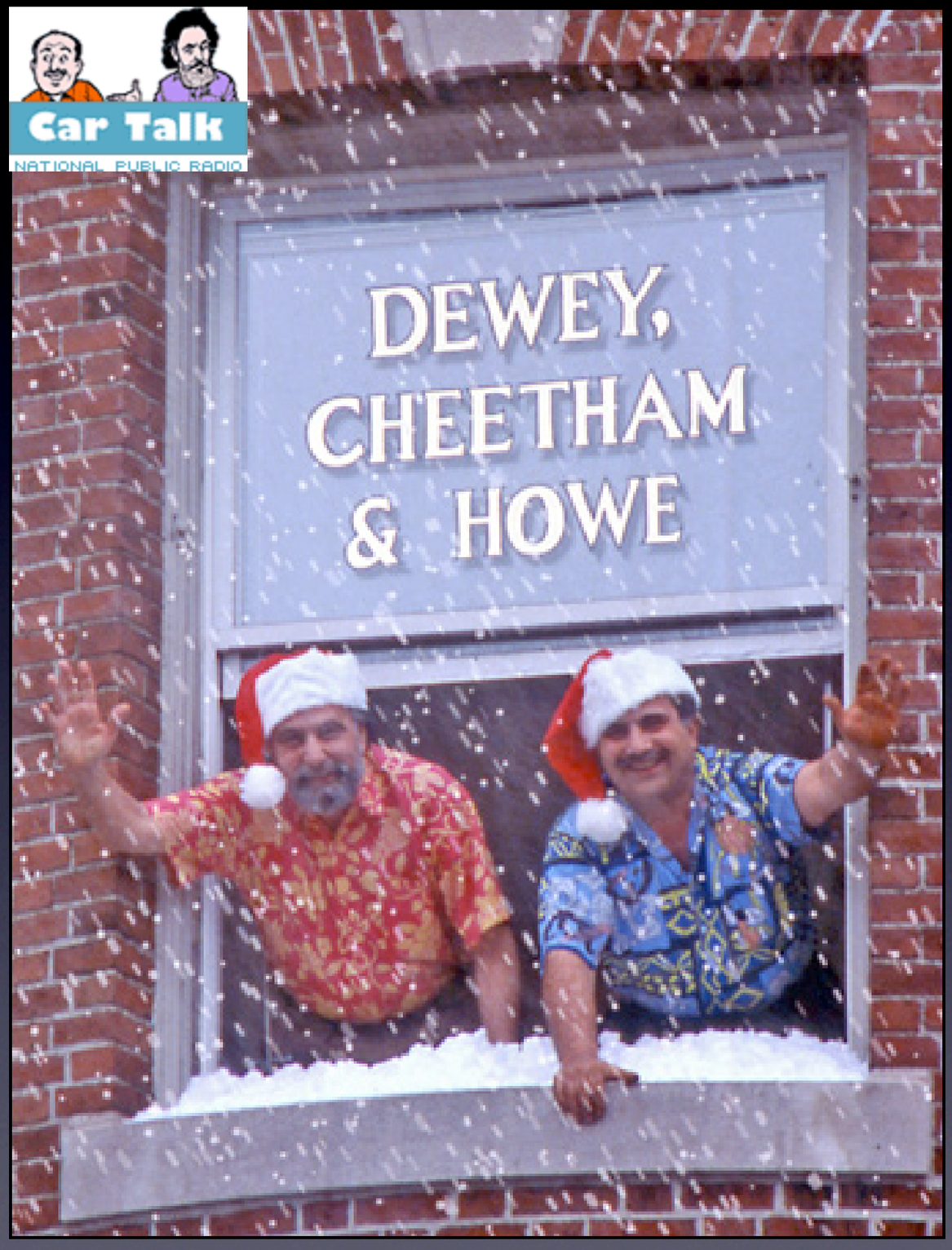
Fermilab Symposium · 22 May 2006

We can understand the Universe.

Nature is reliable, not capricious.

- Identify and scrutinize assumptions
- Hone powers of analysis
- Expand capacity for synthesis

- *Link cause with effect*
- *Search for relevant evidence*
- *Seek the truth without self-deception*


Car Talk
NATIONAL PUBLIC RADIO
DEWEY,
CHEETHAM
& HOWE

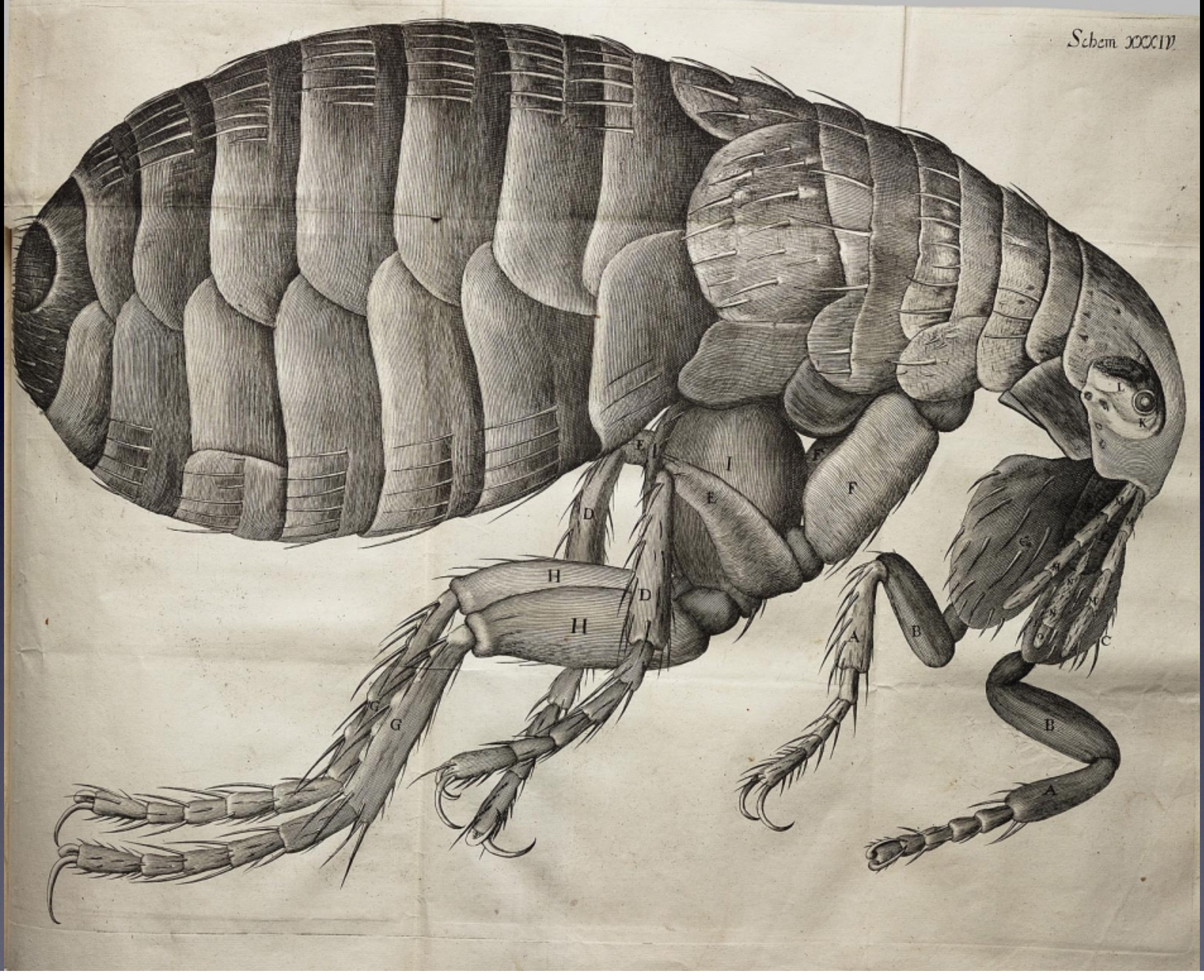
I don't remember a single formula, a single theorem, from three years of college physics. … What I do recall … is certain ways of thinking, of approaching the world. Physics taught me those, and they have remained with me long after the equations faded. What I'm trying to teach my [creative writing] students, then, are ways of thinking … a sensibility.

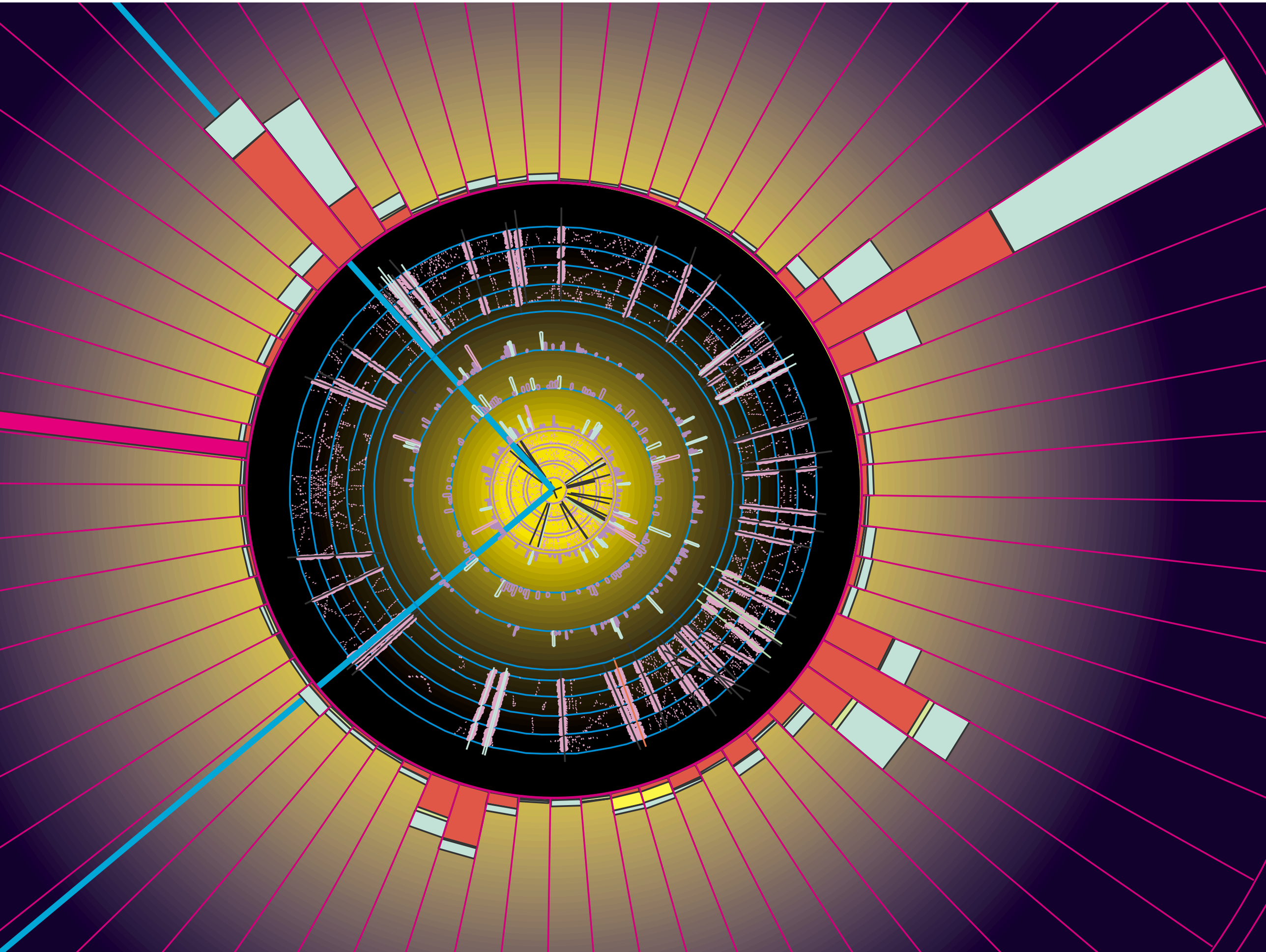
–Peter Ho Davies, Chicago *Tribune* Books 1/9/00

Making observations.

Gathering specimens.

Schem XXXIV.





Observing Fermilab's Prairie

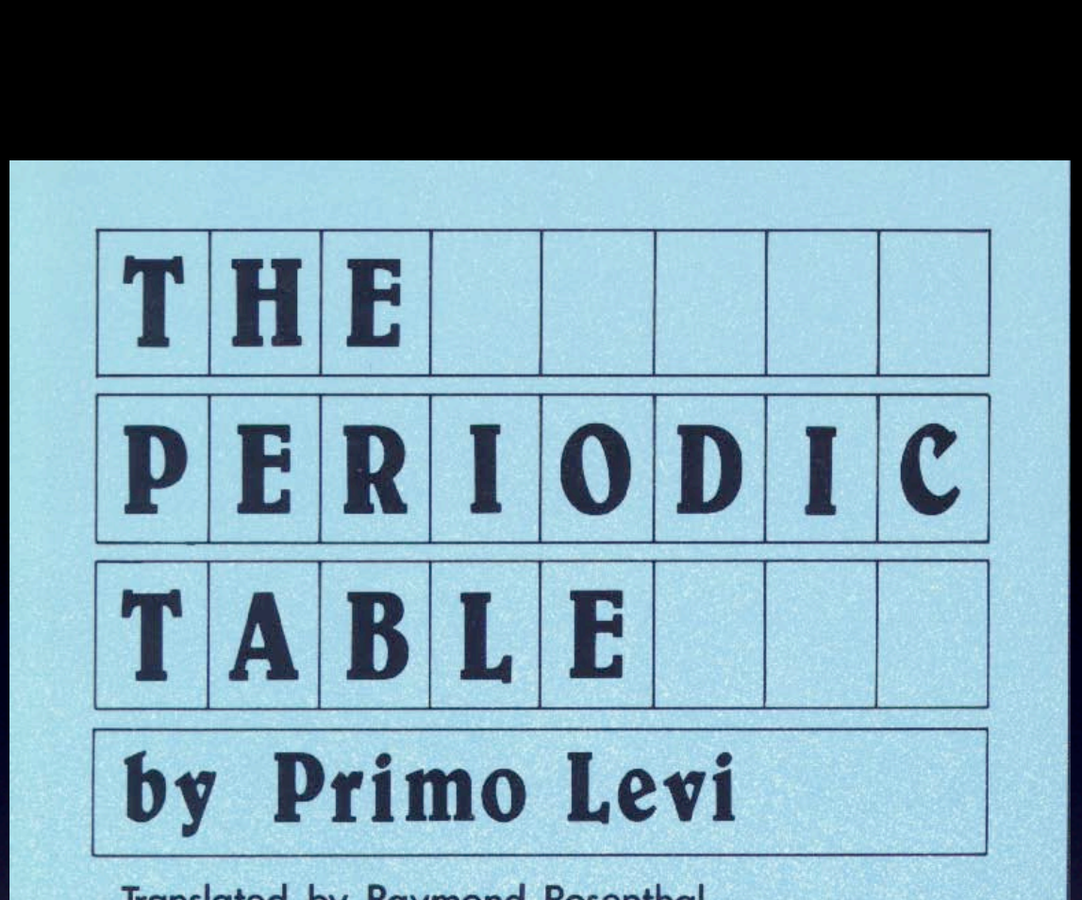
Science is about Nature.

Reality matters.

THE PERIODIC TABLE

by Primo Levi

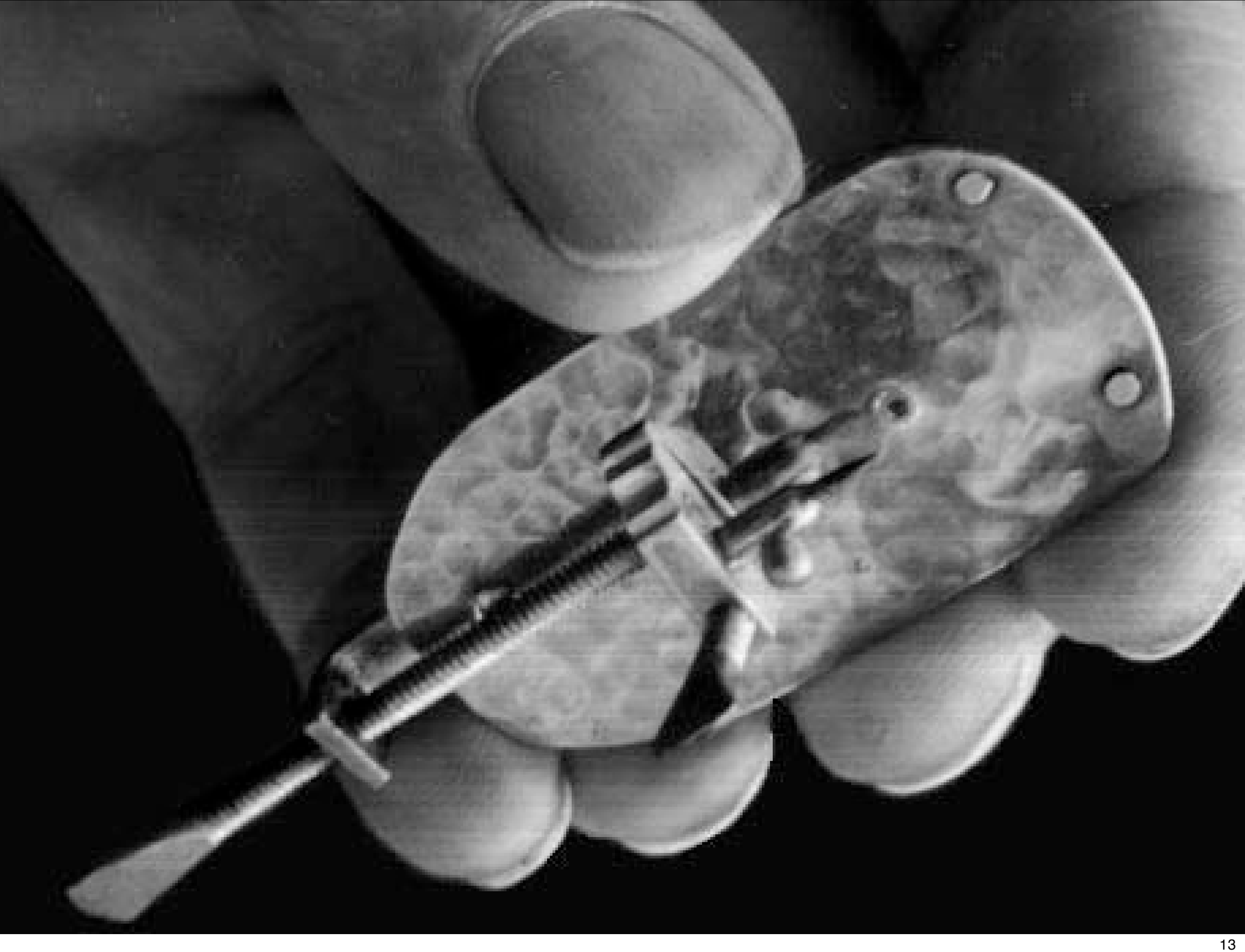
Translated by Raymond Rosenthal

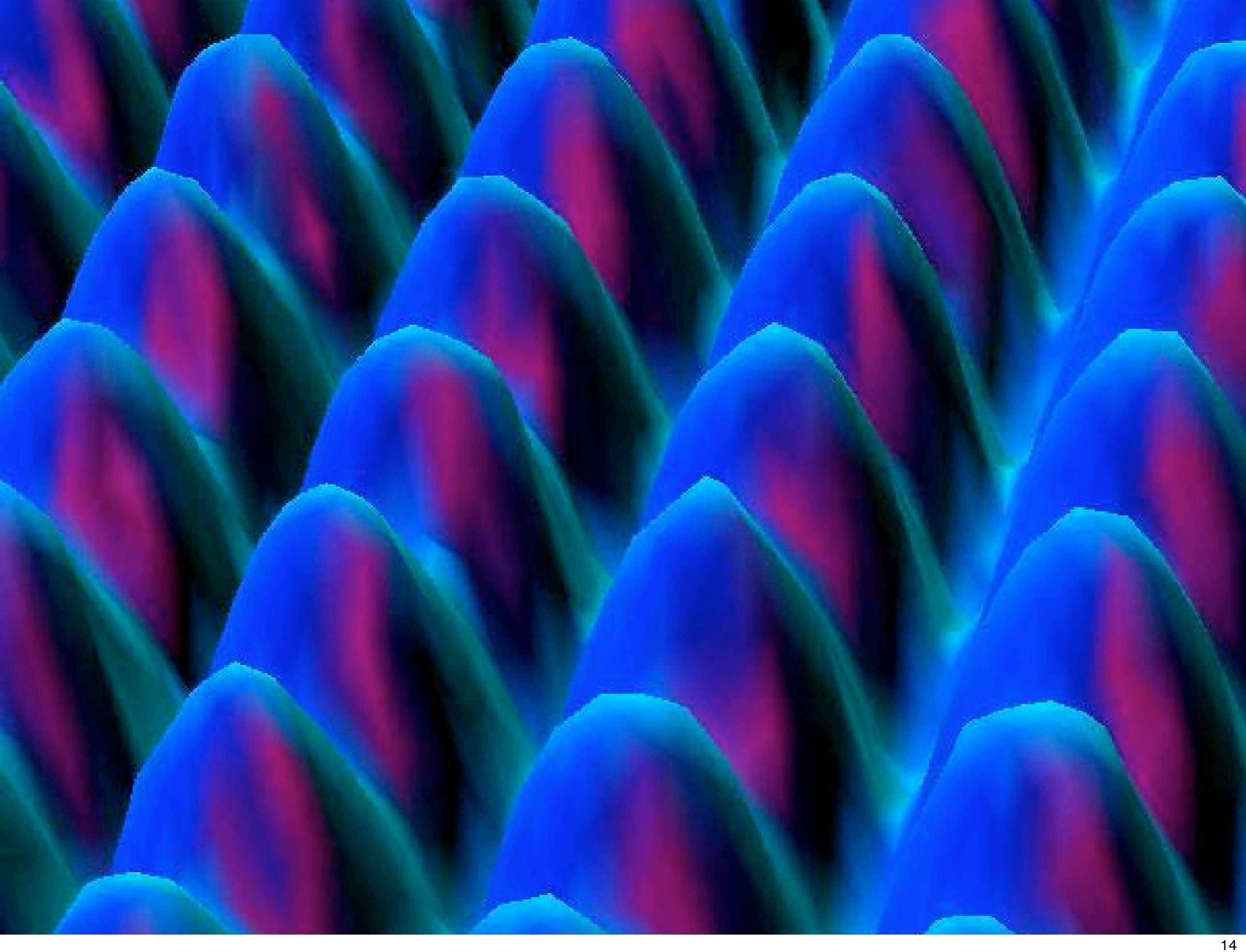


"The book it is *necessary* to read next....I was deeply impressed."
—Saul Bellow

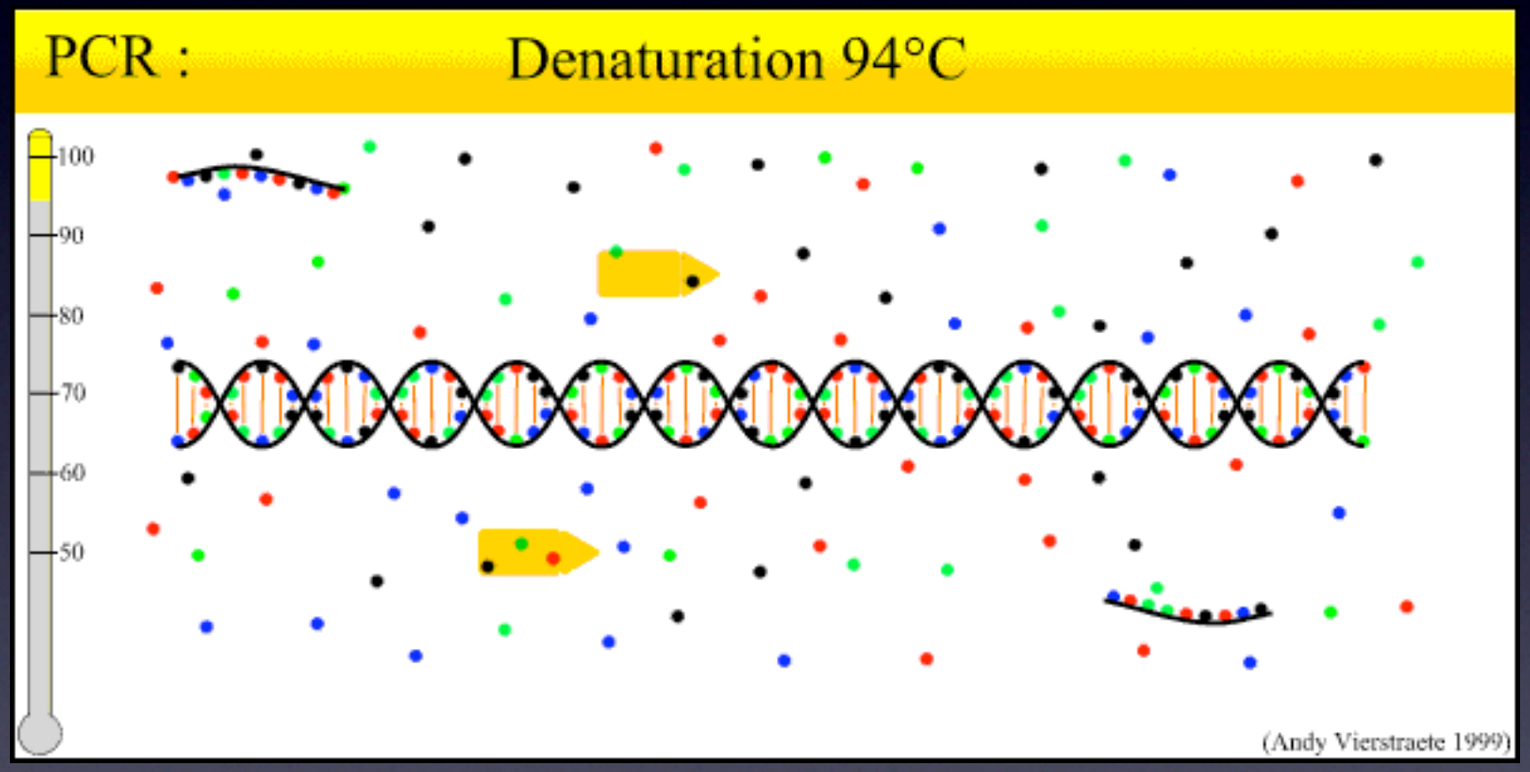
Science enables technology.

Technology enables science.

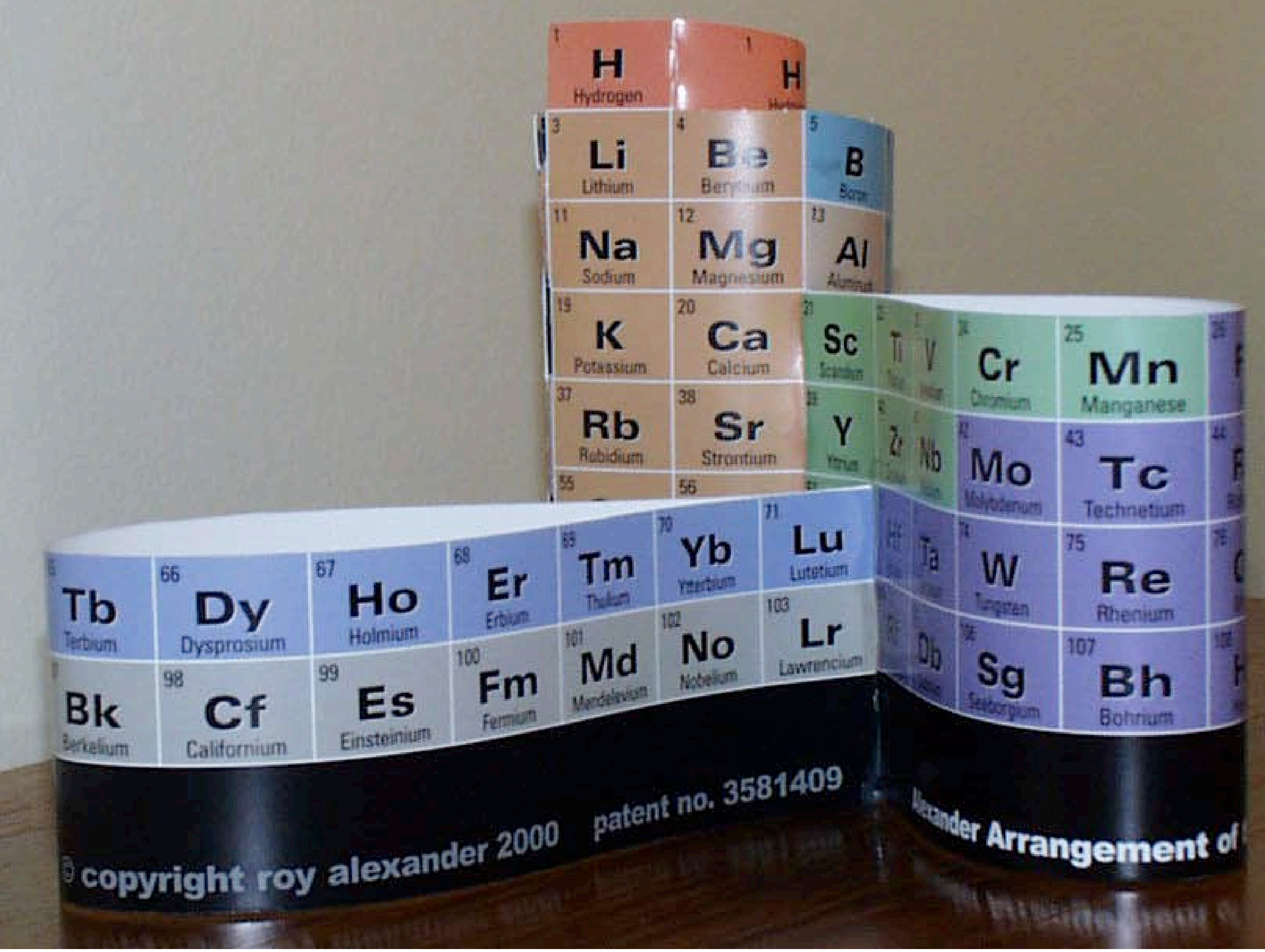




Polymerase Chain Reaction for genetic research.



Making Measurements

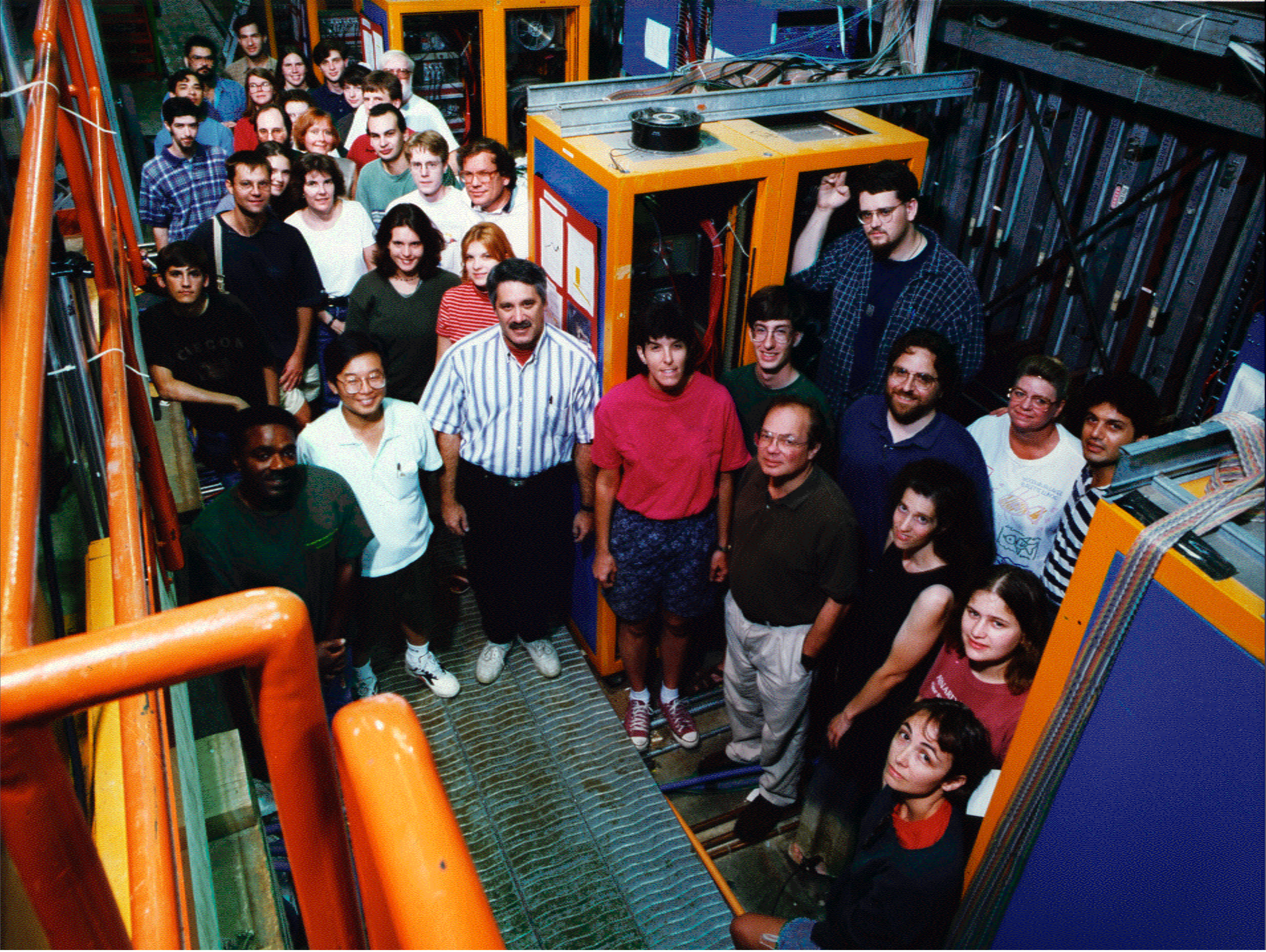

1 H Hydrogen
1 H
3 Li Lithium
4 Be
5 B
11 Na Sodium
12 Mg Magnesium
13 Al
19 K Potassium
20 Ca Calcium
21 Sc
24 Cr Chromium
25 Mn Manganese
37 Rb Rubidium
38 Sr Strontium
39 Y
42 Mo Molybdenum
43 Tc Technetium
55
56
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
73 Ta
74 W Tungsten
75 Re Rhenium
Tb Terbium
Bk Berkelium
98 Cf Californium
99 Es Einsteinium
100 Fm Fermium
101 Md Mendelevium
102 No Nobelium
103 Lr Lawrencium
Db
106 Sg Seaborgium
107 Bh Bohrium
© copyright roy alexander 2000
patent no. 3581409
Alexander Arrangement of

Doing experiments

Nullius in verba!

Don't take anyone's word for anything!

People do science.



How old is the Earth?

Cyclical cosmologies:

Maya · August 11, 3114 B.C.E. – December 21, 2012

Han Chinese · every 23,639,040 years

Genesis (Hebrew Scholars):

Year of Creation was 3764 B.C.E.

Current year is 5766 A.M.

Genesis (J. Lightfoot after Archbishop Ussher, 1654):

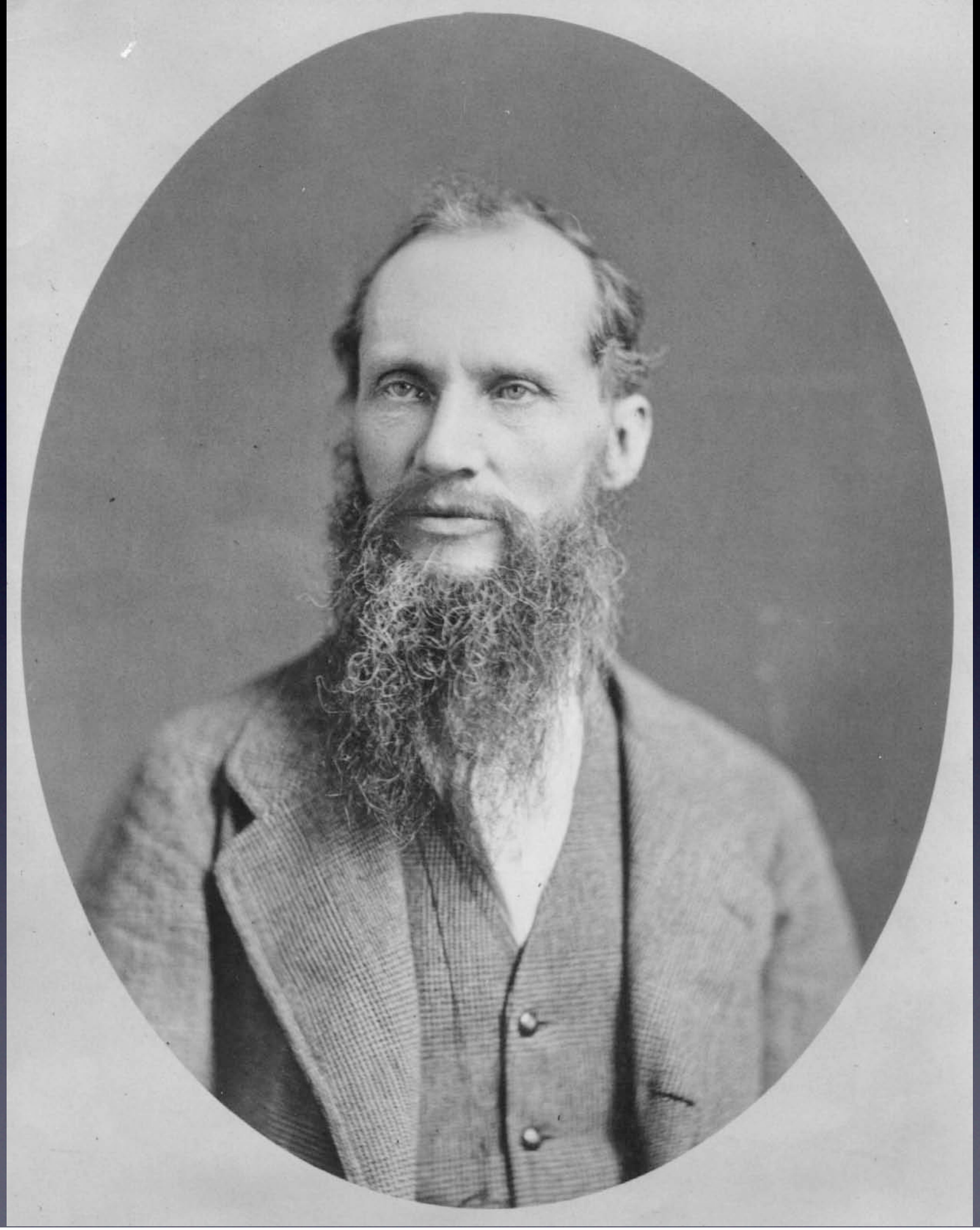
Moment of Creation was October 26, 4004 B.C.E.

at 9:00 a.m. in Mesopotamia.

How old is the Earth?

Uniformitarian geologists (James Hutton, 1795):

"no vestige of a beginning,
no prospect of an end"



William Thomson (Lord Kelvin), 1862

How long for molten Earth to cool?

20 – 40 million years

Challenge to Religious Authority …
and to Darwinian evolution

LORD AND LADY KELVIN IN CORONATION ROBES

Radioactivity reheats the Earth

Isotopic abundances:

Oldest rocks · 3.8 billion years
Primal Earth (meteorites) · 4.5 billion years


RESERVE BANK OF
NEW ZEALAND
100
GOVERNOR
LORD
RUTHERFORD
OF
NELSON
THIS NOTE IS LEGAL TENDER FOR
ONE HUNDRED
DOLLARS
100

WebElements: the periodic table on the world-wide web

http://www.webelements.com/

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen **1** **H** 1.00794(7)																		helium **2** **He** 4.002602(2)
lithium **3** **Li** 6.941(2)	beryllium **4** **Be** 9.012182(3)												boron **5** **B** 10.811(7)	carbon **6** **C** 12.0107(8)	nitrogen **7** **N** 14.00674(7)	oxygen **8** **O** 15.9994(3)	fluorine **9** **F** 18.9984032(5)	neon **10** **Ne** 20.1797(6)
sodium **11** **Na** 22.989770(2)	magnesium **12** **Mg** 24.3050(6)												aluminium **13** **Al** 26.981538(2)	silicon **14** **Si** 28.0855(3)	phosphorus **15** **P** 30.973761(2)	sulfur **16** **S** 32.066(6)	chlorine **17** **Cl** 35.4527(9)	argon **18** **Ar** 39.948(1)
potassium **19** **K** 39.0983(1)	calcium **20** **Ca** 40.078(4)		scandium **21** **Sc** 44.955910(8)	titanium **22** **Ti** 47.867(1)	vanadium **23** **V** 50.9415(1)	chromium **24** **Cr** 51.9961(6)	manganese **25** 54.938049(9)	iron **26** **Fe** 55.845(2)	cobalt **27** **Co** 58.933200(9)	nickel **28** **Ni** 58.6934(2)	copper **29** **Cu** 63.546(3)	zinc **30** **Zn** 65.39(2)	gallium **31** **Ga** 69.723(1)	germanium **32** **Ge** 72.61(2)	arsenic **33** **As** 74.92160(2)	selenium **34** **Se** 78.96(3)	bromine **35** **Br** 79.904(1)	krypton **36** **Kr** 83.80(1)
rubidium **37** **Rb** 85.4678(3)	strontium **38** **Sr** 87.62(1)		yttrium **39** **Y** 88.90585(2)	zirconium **40** **Zr** 91.224(2)	niobium **41** **Nb** 92.90638(2)	molybdenum **42** **Mo** 95.94(1)		ruthenium **44** **Ru** 101.07(2)	rhodium **45** **Rh** 102.90550(2)	palladium **46** **Pd** 106.42(1)	silver **47** **Ag** 107.8682(2)	cadmium **48** **Cd** 112.411(8)	indium **49** **In** 114.818(3)	tin **50** **Sn** 118.710(7)	antimony **51** **Sb** 121.760(1)	tellurium **52** **Te** 127.60(3)	iodine **53** **I** 126.90447(3)	xenon **54** **Xe** 131.29(2)
caesium **55** **Cs** 132.90545(2)	barium **56** **Ba** 137.327(7)	**57-70** *	lutetium **71** **Lu** 174.967(1)		tantalum **73** **Ta** 180.9479(1)	tungsten **74** **W** 183.84(1)		osmium **76** **Os** 190.23(3)	iridium **77** **Ir** 192.217(3)	platinum **78** **Pt** 195.078(2)	gold **79** **Au** 196.96655(2)	mercury **80** **Hg** 200.59(2)	thallium **81** **Tl** 204.3833(2)	lead **82** **Pb** 207.2(1)	bismuth **83** **Bi** 208.98038(2)	polonium **84** **Po** [208.9824]		radon **86** **Rn** [222.0176]
	radium **88** **Ra** [226.0254]	**89-102** **	lawrencium **103** **Lr** [262.110]	rutherfordium **104** **Rf** [261.1089]	dubnium **105** **Db** [262.1144]	seaborgium **106** **Sg** [263.1186]	bohrium **107** **Bh** [264.12]	hassium **108** **Hs** [265.1306]	meitnerium **109** **Mt** [268]	ununnilium **110** **Uun** [269]	ununnium **111** **Uuu** [272]	ununbium **112** **Uub** [277]		ununquadium **114** **Uuq** [289]		ununhexium **116** **Uuh** [289]		ununoctium **118** **Uuo** [293]

Key:

element name
atomic number
element symbol
1997 atomic weight (mean relative mass)

*lanthanides	lanthanum **57** **La** 138.9055(2)	cerium **58** **Ce** 140.116(1)	praseodymium **59** **Pr** 140.90765(2)	neodymium **60** **Nd** 144.24(3)		samarium **62** **Sm** 150.36(3)	europium **63** **Eu** 151.964(1)	gadolinium **64** **Gd** 157.25(3)	terbium **65** **Tb** 158.92534(2)	dysprosium **66** **Dy** 162.50(3)	holmium **67** **Ho** 164.93032(2)	erbium **68** **Er** 167.26(3)	thulium **69** **Tm** 168.93421(2)	ytterbium **70** **Yb** 173.04(3)
**actinides	actinium **89** **Ac** [227.0277]	thorium **90** **Th** 232.0381(1)	protactinium **91** **Pa** 231.03588(2)	uranium **92** **U** 238.0289(1)	**93** **Np** [237.0482]	plutonium **94** **Pu** [244.0642]	americium **95** **Am** [243.0614]	curium **96** **Cm** [247.0703]	berkelium **97** **Bk** [247.0703]	californium **98** **Cf** [251.0796]	einsteinium **99** **Es** [252.0830]	fermium **100** **Fm** [257.0951]	mendelevium **101** **Md** [258.0984]	nobelium **102** **No** [259.1011]

Symbols and names: the symbols of the elements, their names, and their spellings are those recommended by IUPAC. After some controversy, the names of elements 101-109 are now confirmed: see Pure & Appl. Chem., 1997, **69**, 2471–2473. Names have not been proposed as yet for the most recently discovered elements 110–112, 114, 116, and 118 so those used here are IUPAC's temporary systematic names: see Pure & Appl. Chem., 1979, **51**, 381–384. In the USA and some other countries, the spellings aluminum and cesium are normal while in the UK and elsewhere the usual spelling is sulphur.
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WebElements: the periodic table on the world-wide web

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sodium **11** Na 22.989770(2)	magnesium **12** Mg 24.3050(6)												aluminium **13** Al 26.981538(2)	silicon **14** Si 28.0855(3)	phosphorus **15** P 30.973761(2)	sulfur **16** S 32.066(6)	chlorine **17** Cl 35.4527(9)	argon **18** Ar 39.948(1)
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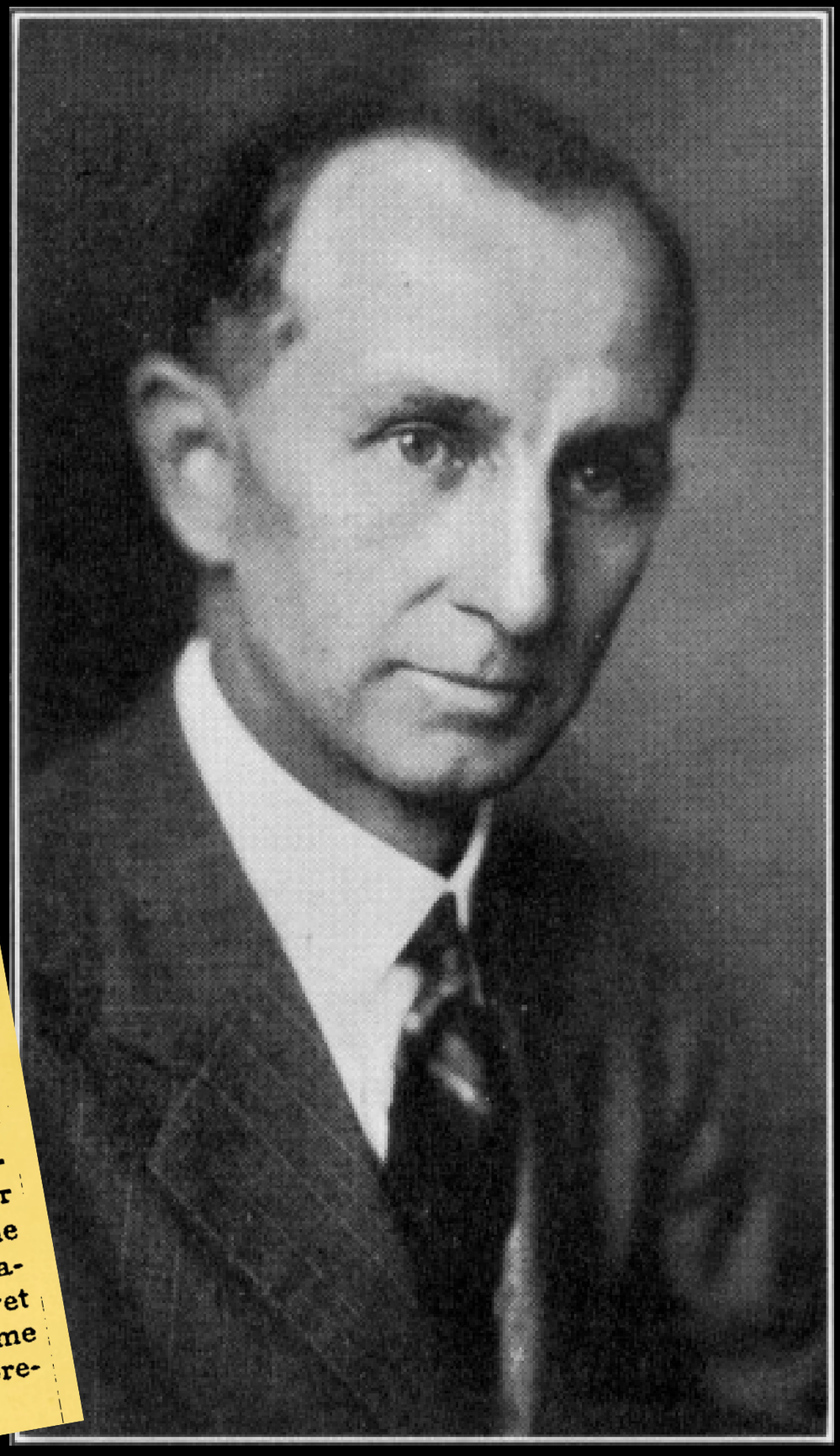
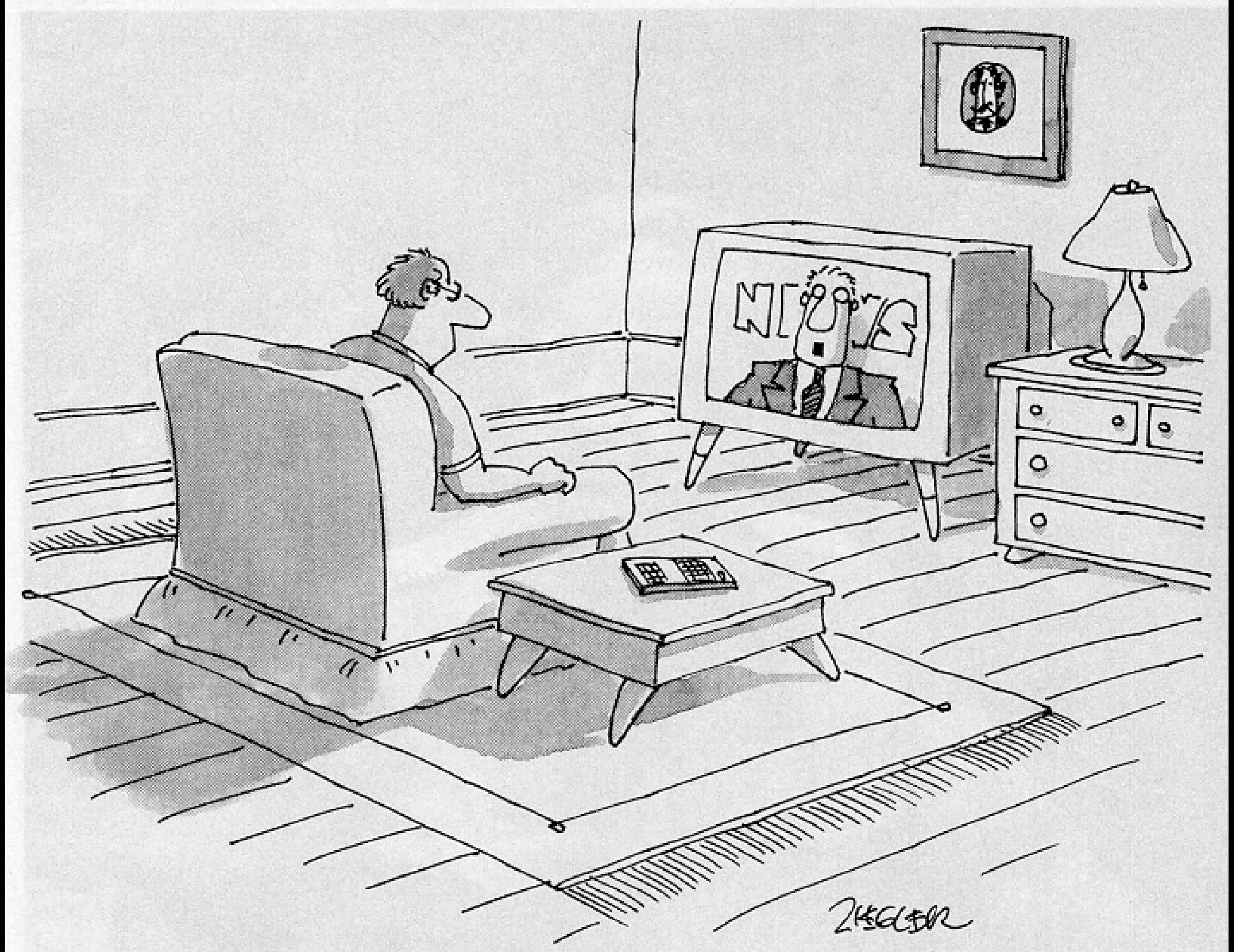
Illinium Is the Name Chosen.

The discoverer of the element No. 61 which has revealed its identity through the medium of X-rays has christened it "Illinium," in recognition of the support which the State of Illinois has given to the university in which the work was done. It is an appropriate and euphonious name, recalling not only the State and its university but the aboriginal inhabitants, the Indians who called themselves Illini, the name in their language for "men."

So it is the "Land of Men" in which this rare earth was discovered—a more generic name than "Americanium," which was suggested. Whether this rare earth was actually deposited in Illinois in bygone ages or was imported from some other State or country is not announced. Probably it is like some of that most rare earth, which Illinois discovered, gave to the world and then brought back to burial in its own prairie soil, in the person of ABRAHAM LINCOLN, in that it, too, had its origin in another region.

But whatever the source of Illinium, it will be associated with the State of LINCOLN and will permanently represent America in the great world Assembly of Elements. There is a chance that there may be still further representation, as four elements remain to be identified, and any one or all of them may be discovered in the same or some other American laboratory. In that event, there may yet be an element which will bear a name in which all the States will be represented.





"Scientists confirmed today that everything we know about the structure of the universe is wrongedy-wrong-wrong."

Making Connections

Intuition is empathy.

Knowing how things will turn out

Learning to hear the poetry of Nature

Science is radically conservative.

Introduce assumptions reluctantly
Formulate assumptions precisely
Draw conclusions broadly

Science celebrates doubt.

“the humility of the intellect …”

The Importance of Knowing What We Don't Know

Good scientific advice
may be frustratingly conditional.

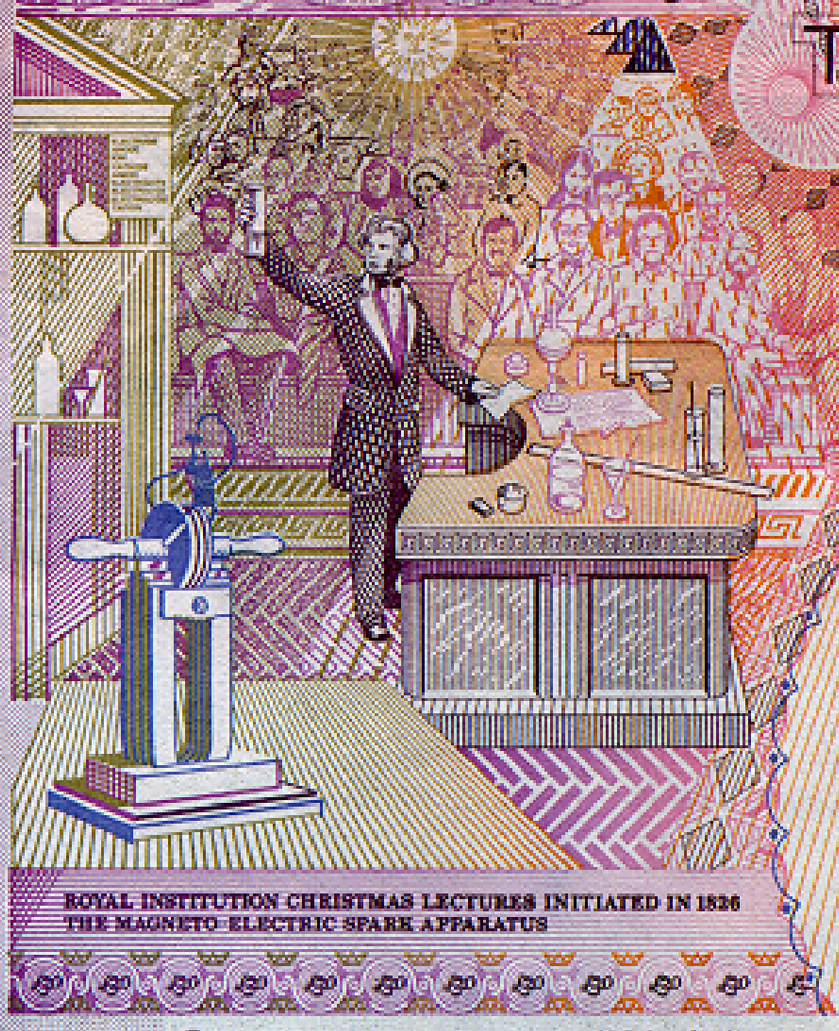
Sometimes …

- *We don't know enough to give a straight answer*
- *Nature can't be pinned down*

£20 BANK of ENGLAND £20

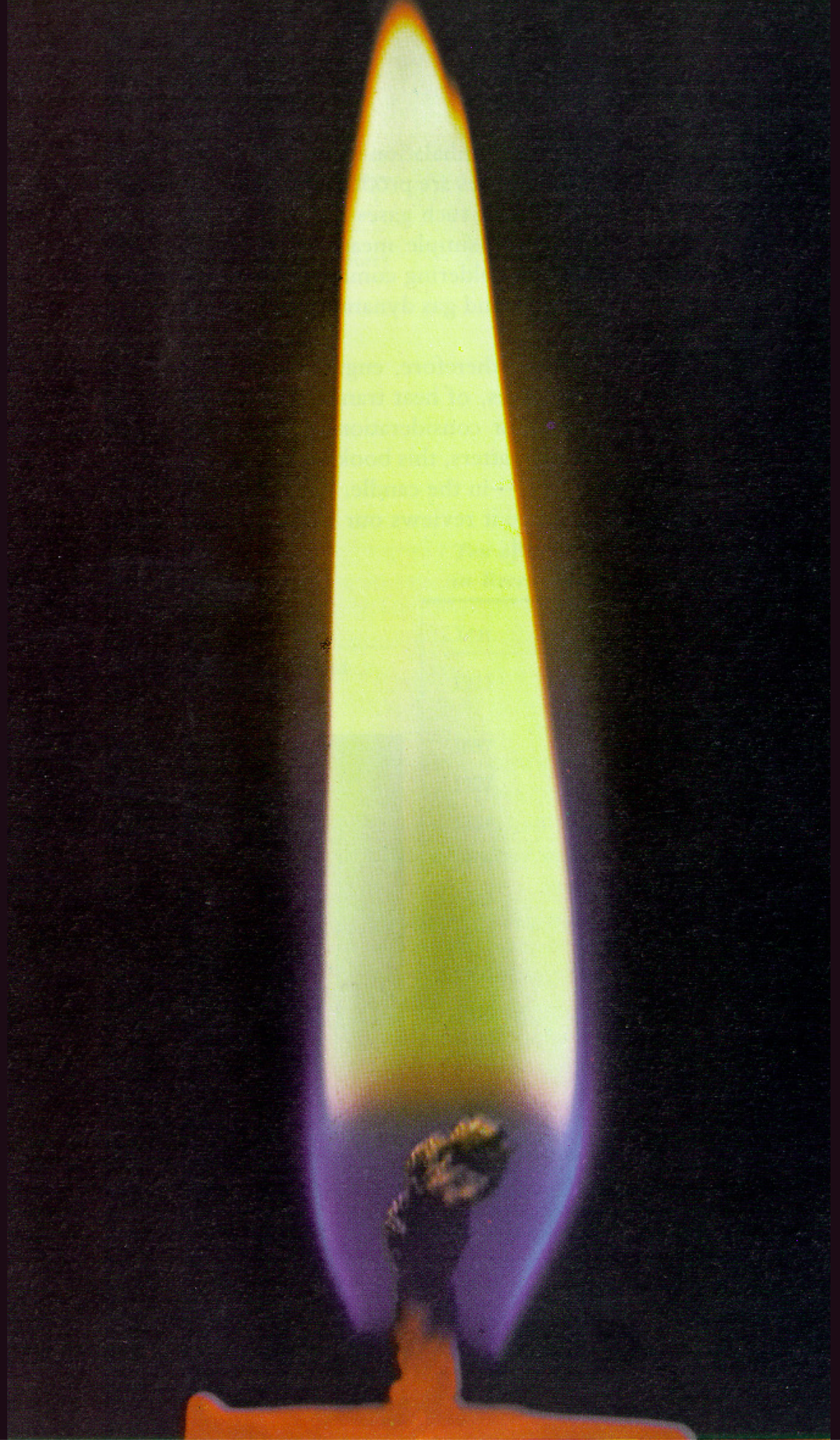
TWENTY

POUNDS



ROYAL INSTITUTION CHRISTMAS LECTURES INITIATED IN 1826
THE MAGNETO ELECTRIC SPARK APPARATUS

Michael Faraday 1791-1867

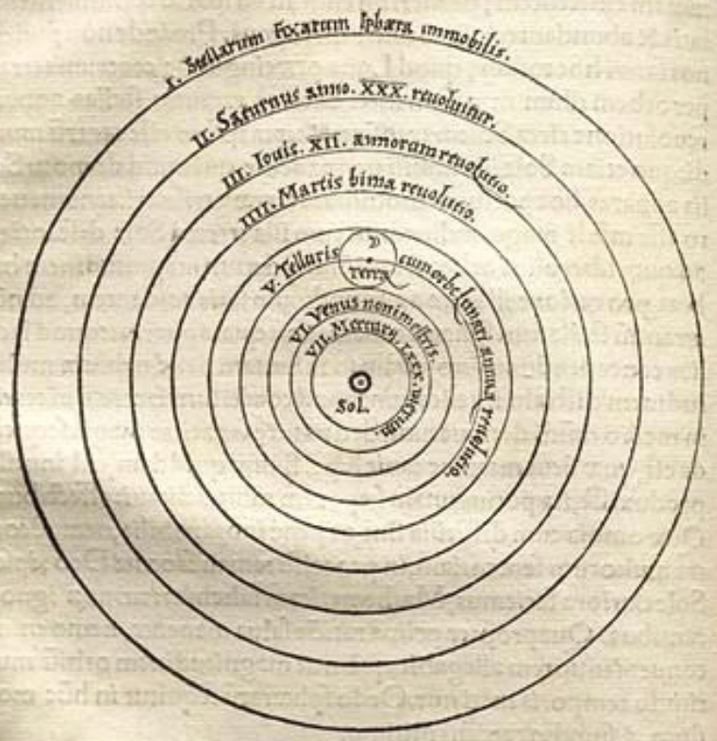


Moral Choices

Science can inform, not resolve.

Science changes the way we see ourselves, and our world.

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

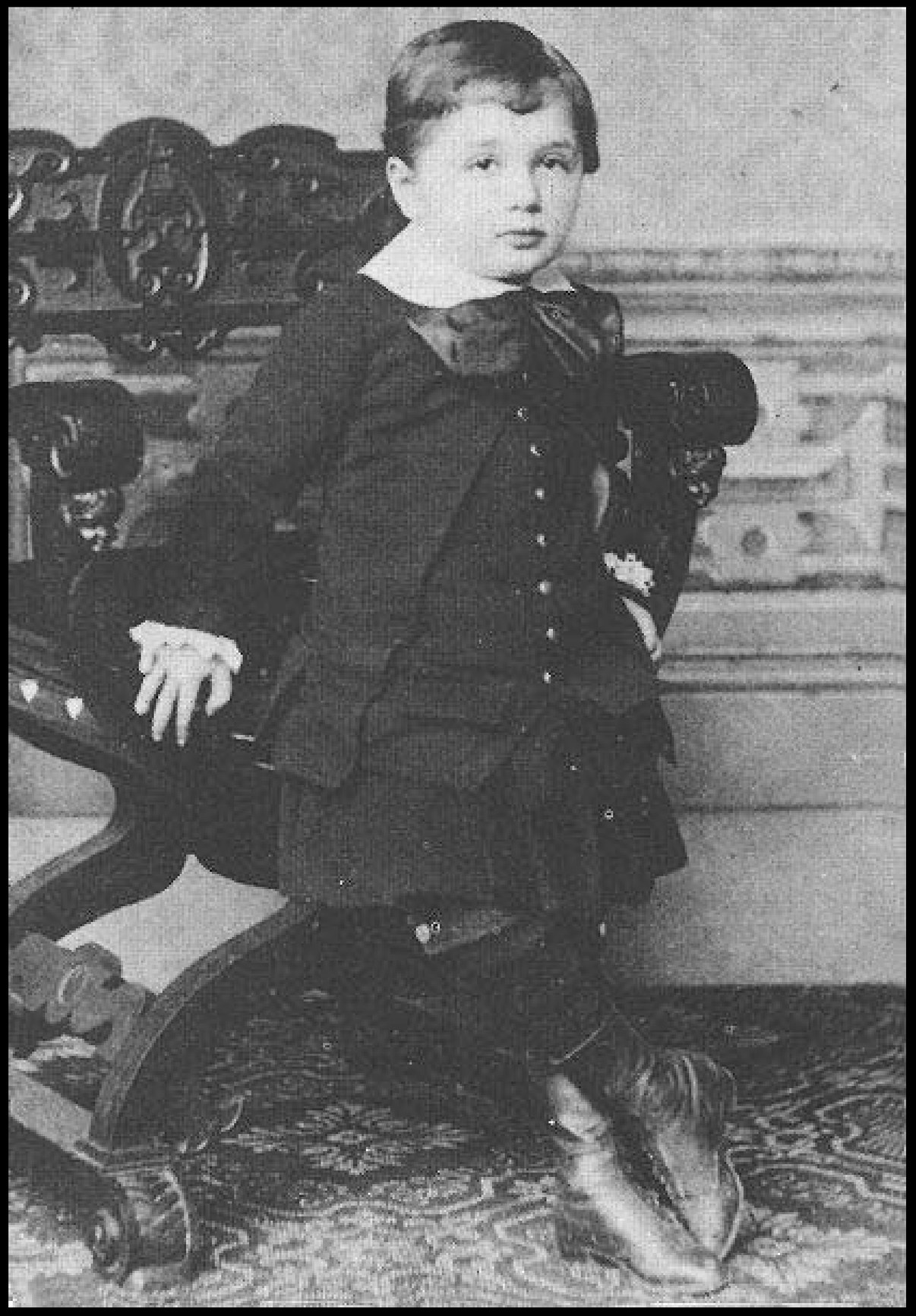


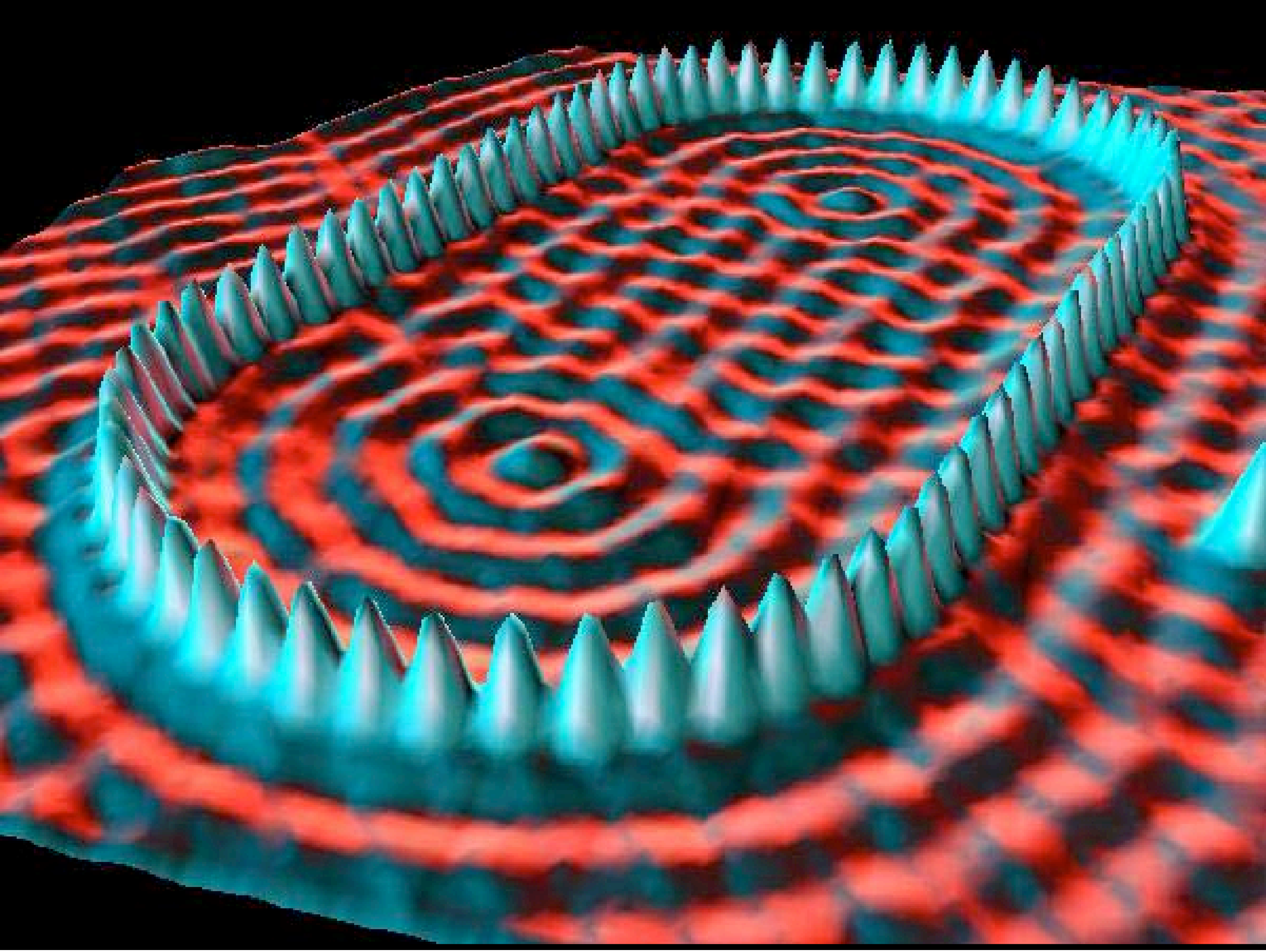
pulcherimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophodis Electra intuentẽ omnia. Ita profecto tanquam in solio re gali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

hac ordinatione admirandam mundi symmetriam, ac certũ harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non potest. Hic enim licet animaduertere, nõ segniter contemplanti, cur maior in Ioue progressus & regressus appareat, quàm in Saturno, & minor quàm in Marte: ac rursus maior in Venere quàm in Mercurio. Quodq; frequentior appareat in Saturno talis reciprocatio, quàm in Ioue: rarior adhuc in Marte, & in Venere, quàm in Mercurio. Præterea quòd Saturnus, Iupiter, & Mars acronycti propinquiores sint terræ, quàm circa eorũ occultationem & apparitionem. Maxime uero Mars pernox factus magnitudine Iouem æquare uidetur, colore duntaxat rutilo discretus: illic autem uix inter secundæ magnitudinis stellas inuenitur, sedula obseruatione sectantibus cognitus. Quæ omnia ex eadem causa procedunt, quæ in telluris est motu. Quòd autem nihil eorum apparet in fixis, immensam illorũ arguit celsitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniã omne uisibile longitudinem distantiæ habet aliquam, ultra quam non amplius spectatur, ut demonstratur in Opticis. Quòd enim à supremo errantium Saturno ad fixarum sphæram adhuc plurimum intersit, scintillantia illorum lumina demõstrant. Quo indicio maxime discernuntur à planetis, quodq; inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diuina hæc Opt. Max. fabrica.

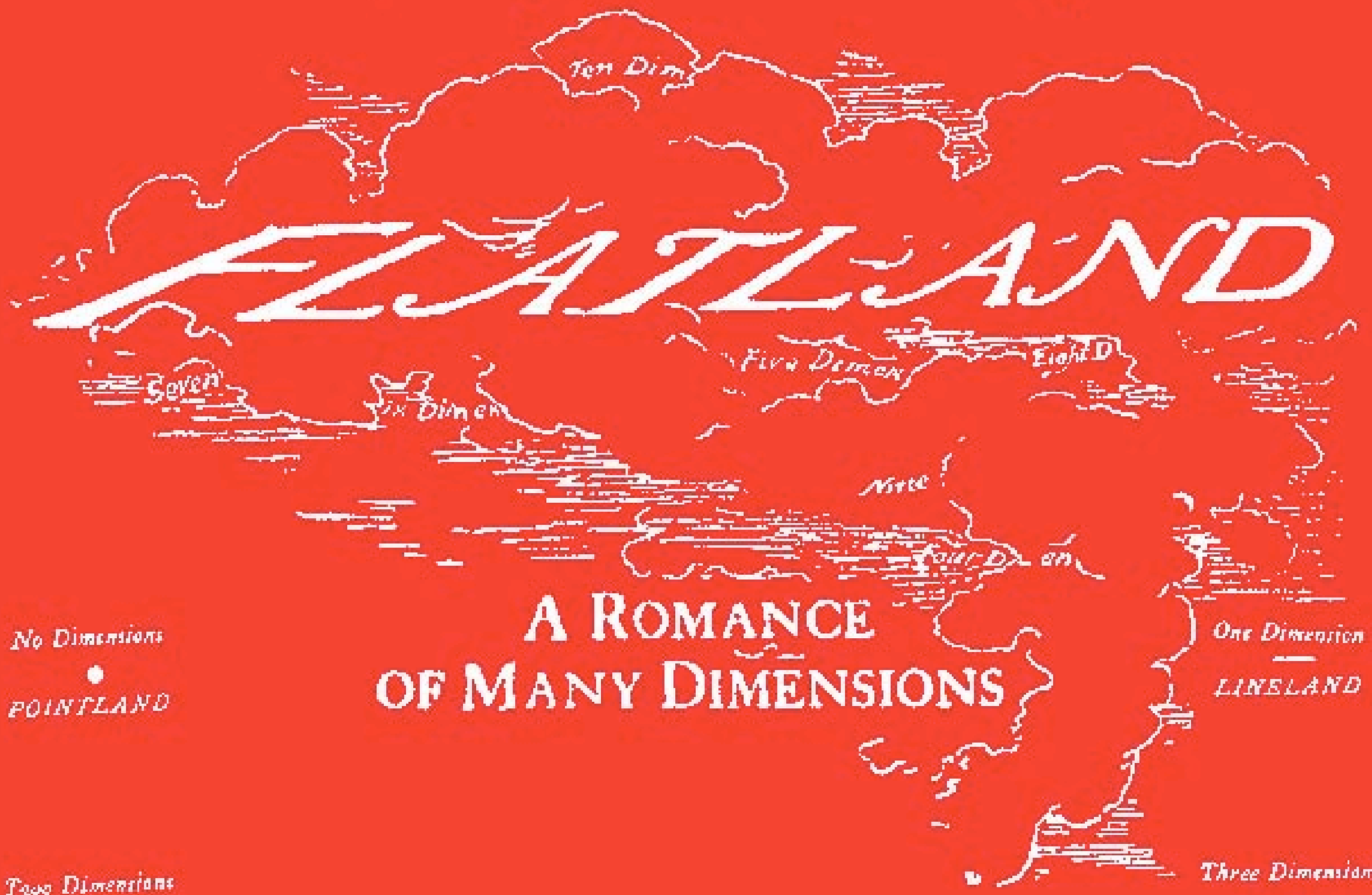
De triplici motu telluris demonstratio. Cap. XI.

CVm igitur mobilitati terrenę tot tantaq; errantium syderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquã hypotesim demonstrentur, quẽ triplicẽ omnino oportet admittere. Primum quem diximus νυχθημερινον à Græcis uocari, diei noctisq; circuitum proprium, circa axem telluris, ab occasu in ortum uergentem, prout in diuersum mundus ferri putatur, æquinoctialem circulum describendo, quem nonnulli æquidialem dicunt, imitantes significationem Græcorũ,

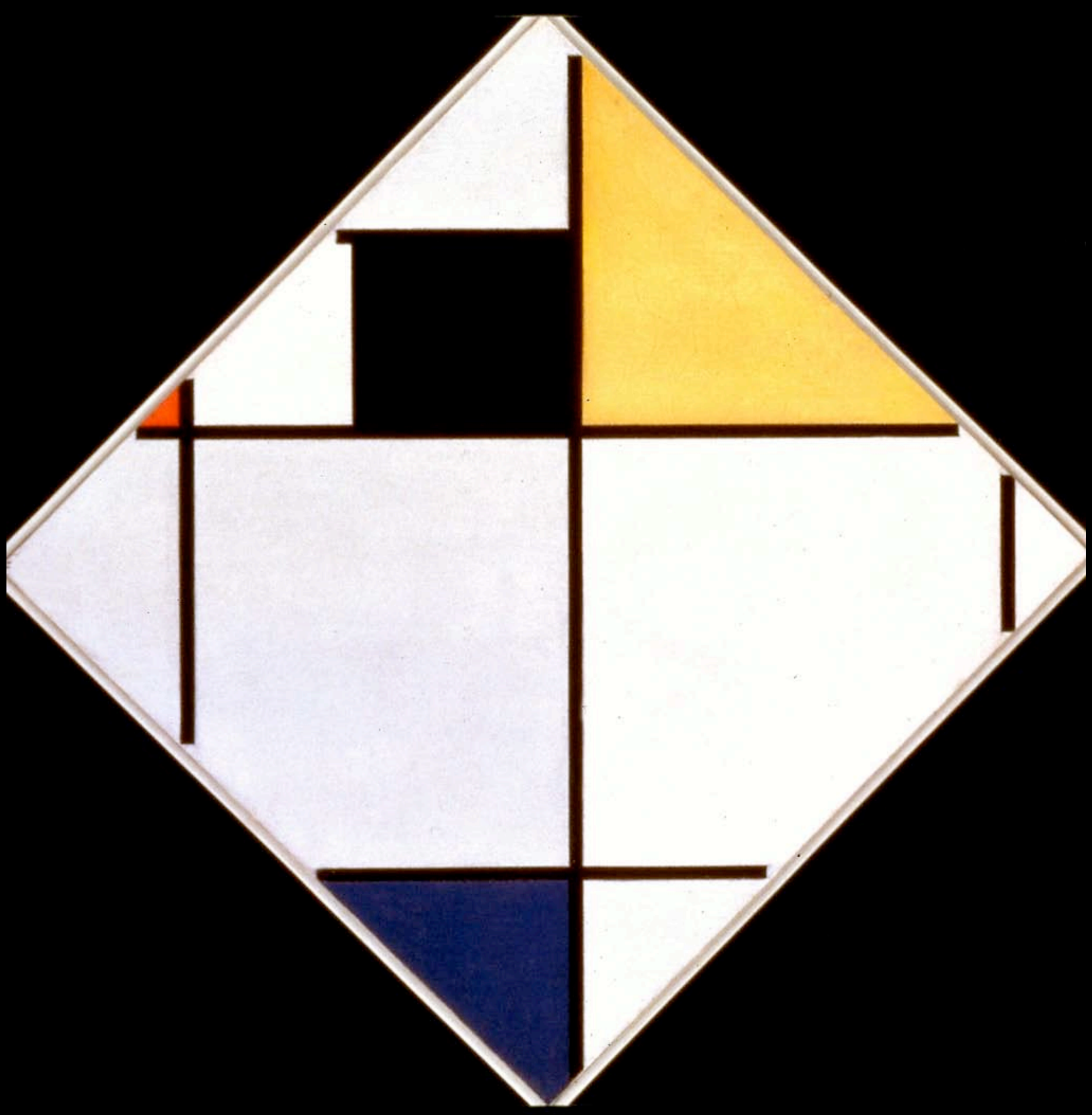




"O day and night, but this is wondrous strange"



Creativity in Art and Science



Why not?