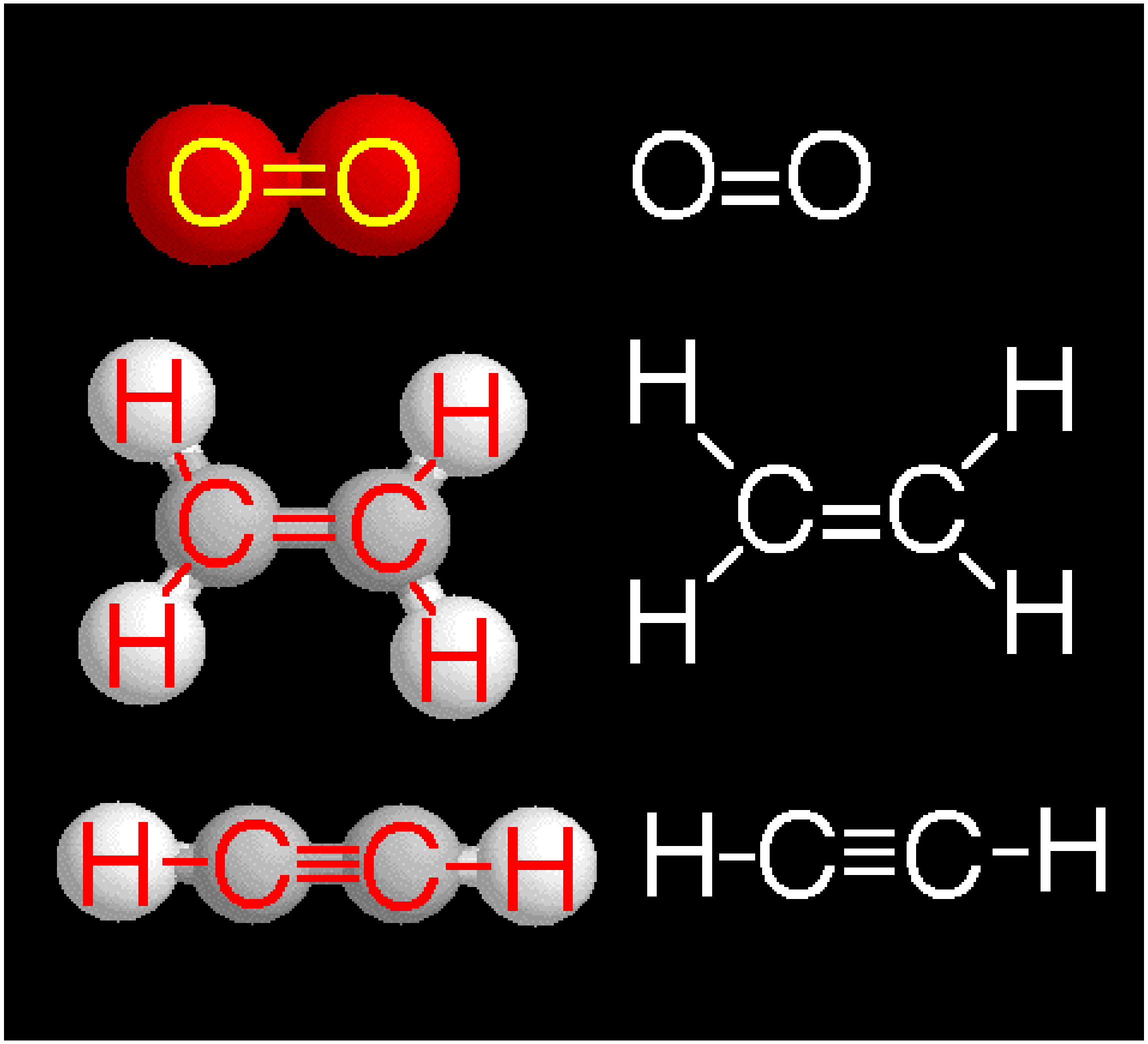
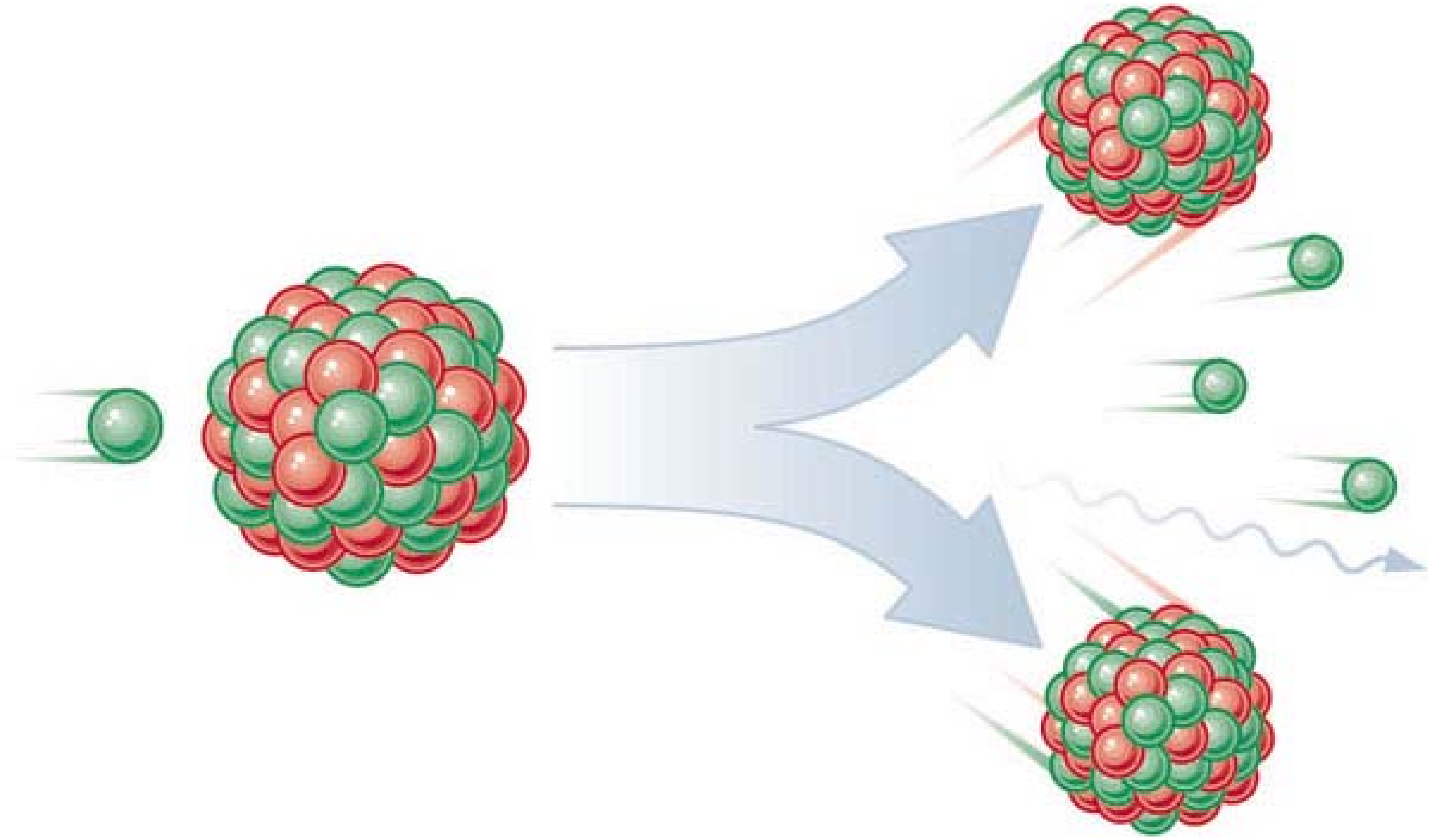
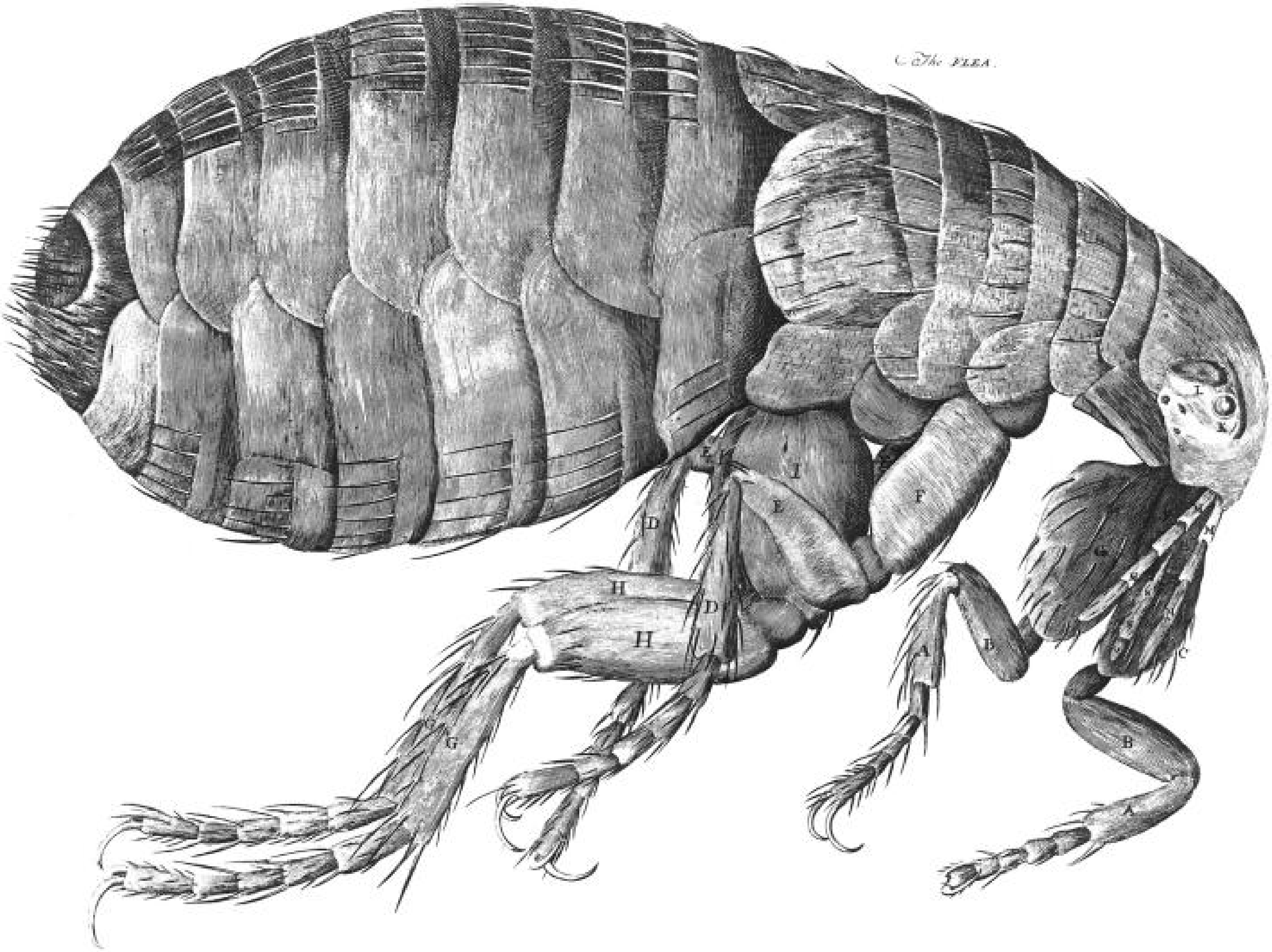
ENERGY



Break a single molecular bond: 10^{-18} J

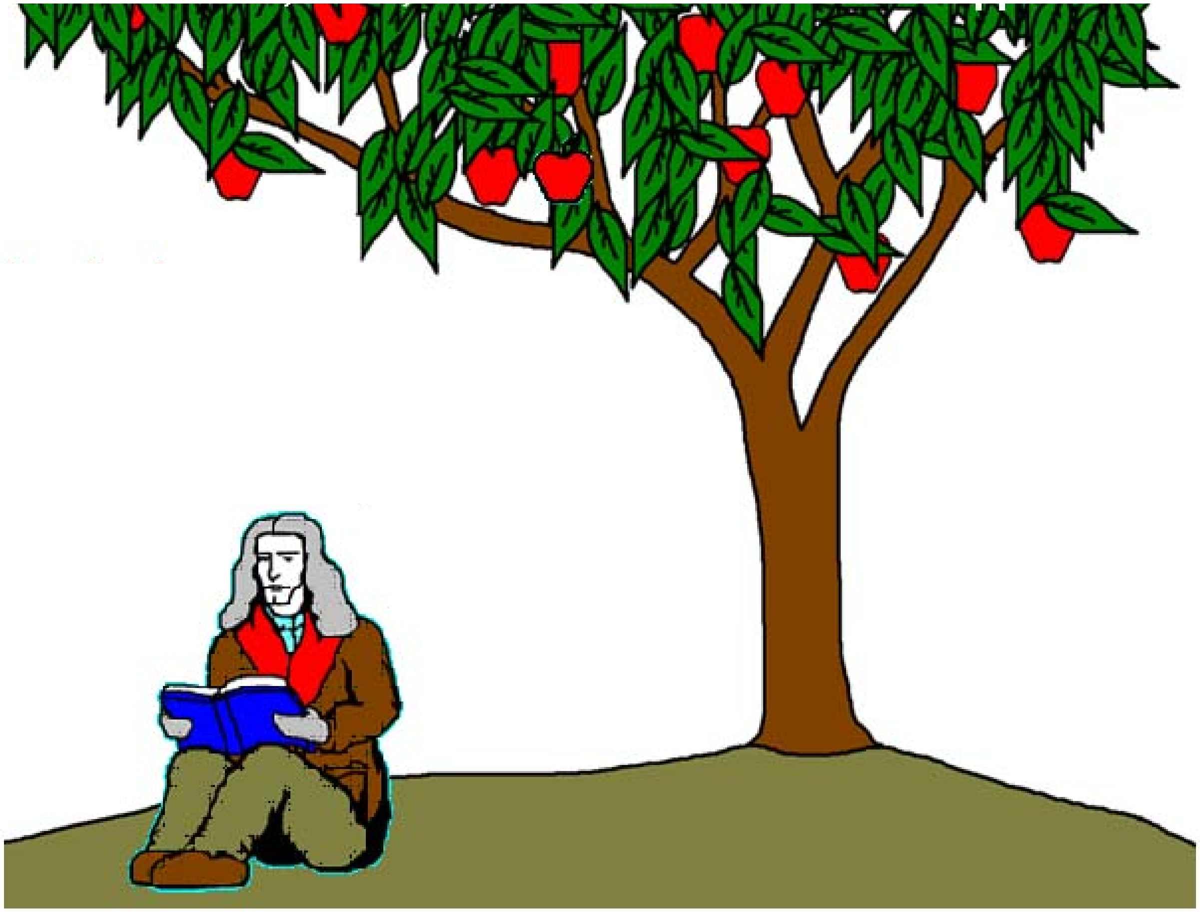


Split a single nucleus: 10^{-11} J



Hopping flea: 10^{-7} J

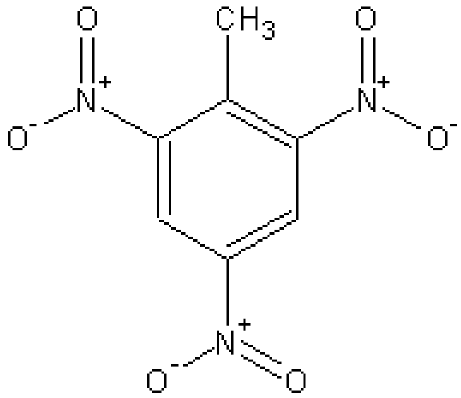
Depress a keyboard key: 10^{-2} J



Newton’s Apple: 1 J

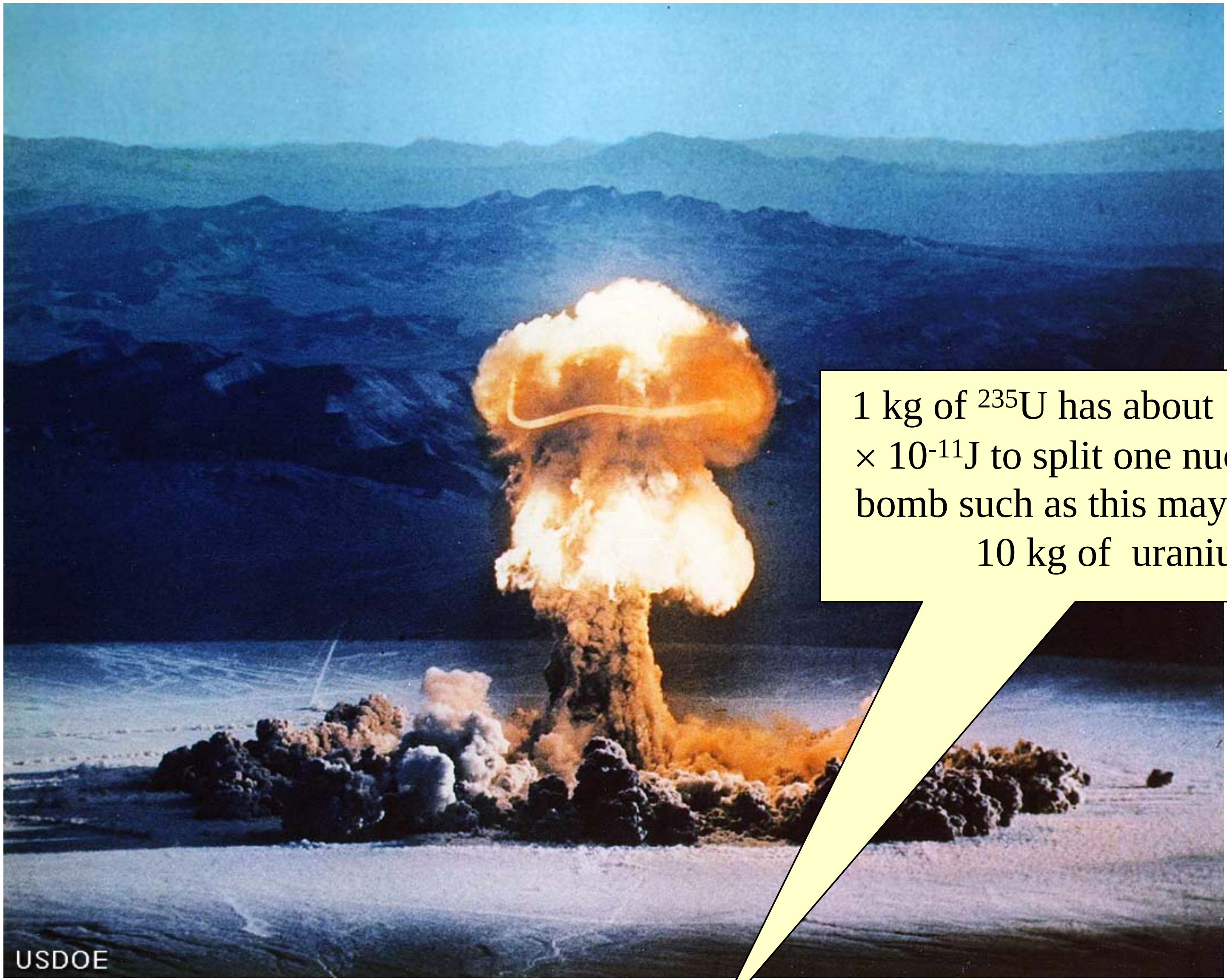
1 kg of TNT has about 10^{24} molecules × 10^{-18}J to break one bond per molecule

1 kg of TNT: 10^6 J



Gallon of gasoline: 10^8 J

Lightning bolt: 10^{10} J



1 kg of ^{235}U has about 10^{24} nuclei $\times 10^{-11}$J to split one nucleus. So a bomb such as this may have only 10 kg of uranium.

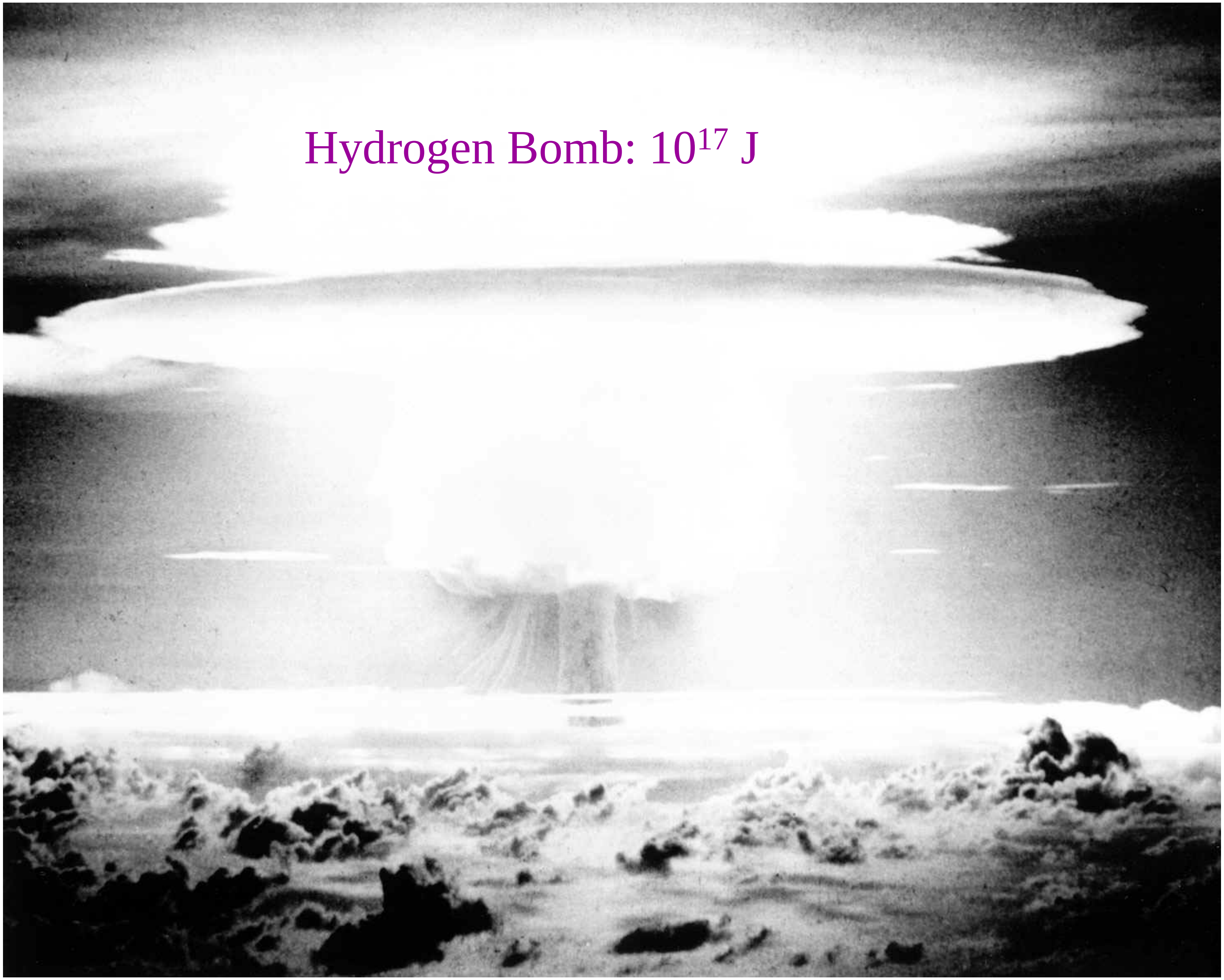
Atomic Bomb (Fission): 10^{14} J

The explosive “yield” is often quoted in kilotons of TNT.

10^{14} J would require 10 kton = 10,000,000 kg of TNT.

The Hiroshima bomb was 15 kton.

Meteor Impact: 10^{16} J

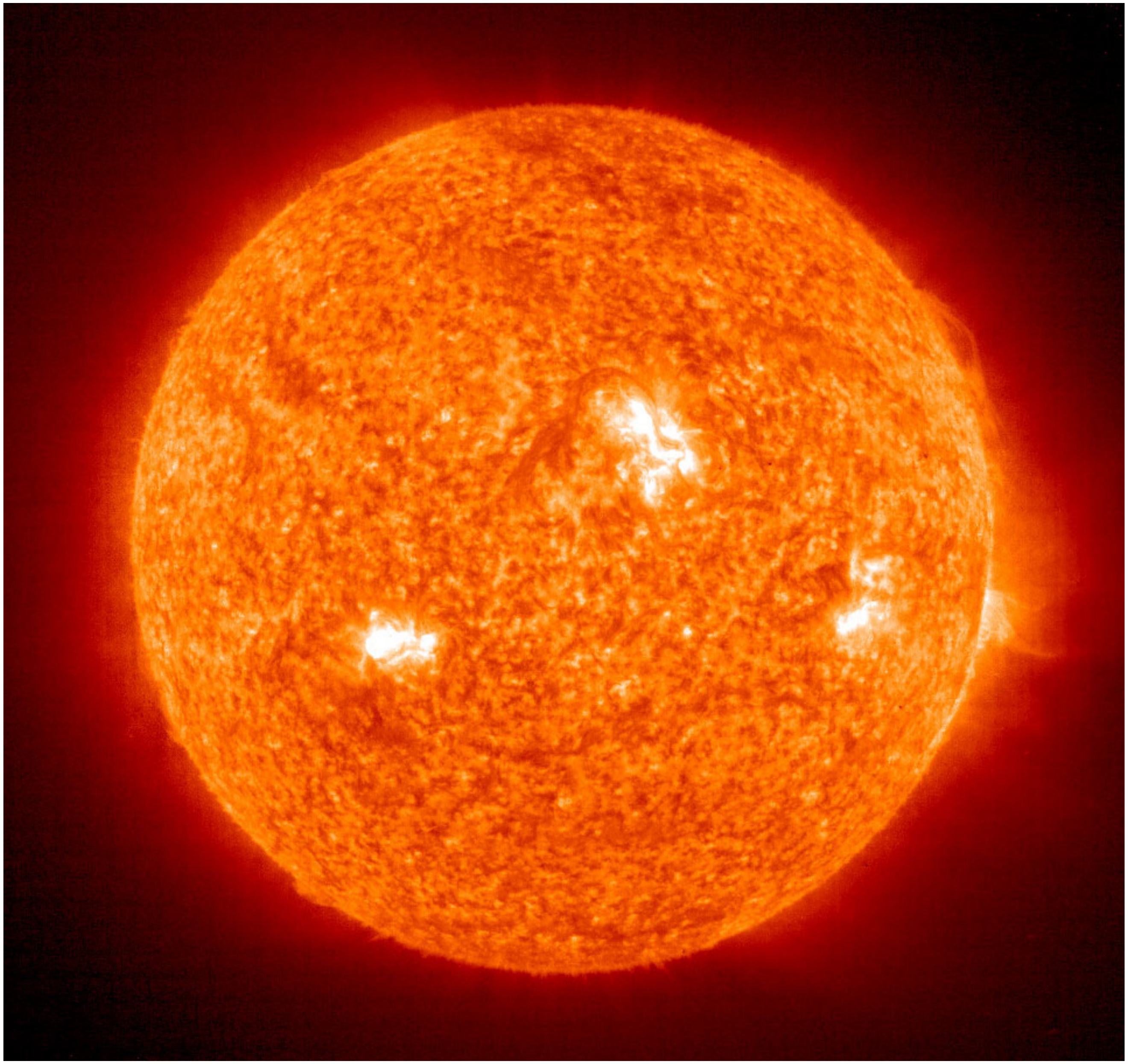


Hydrogen Bomb: 10^{17} J

Exploding volcano: 10^{18} J

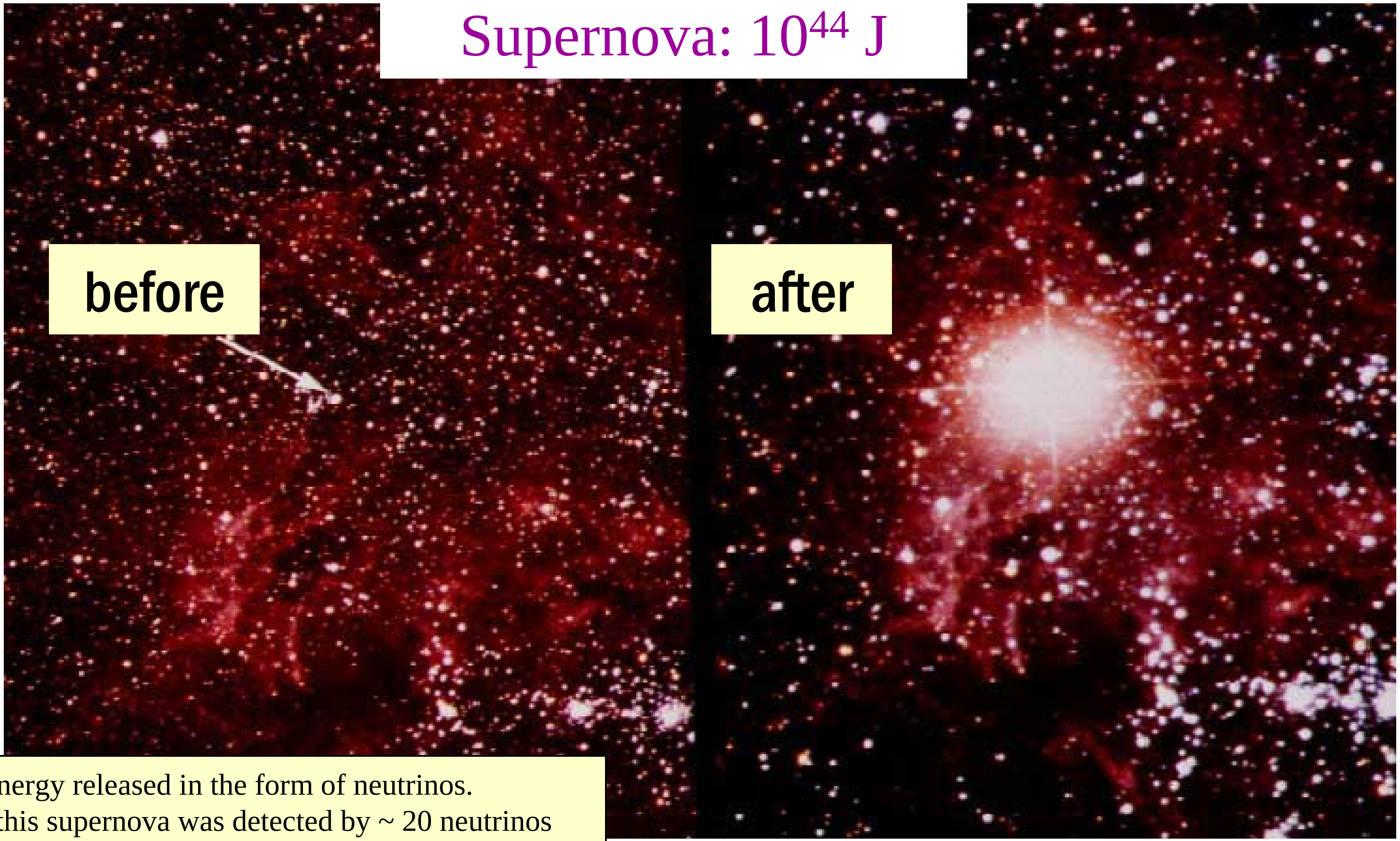
1994: Comet Shoemaker-Levy strikes Jupiter

Fragment G: 10^{22} J

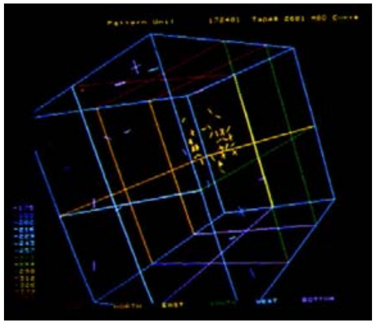


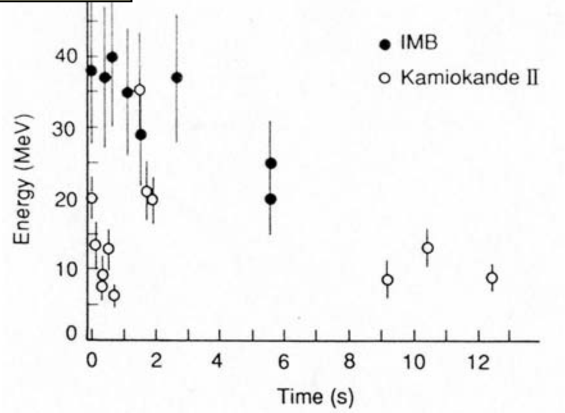
Output of our sun for one year: 10^{34} J

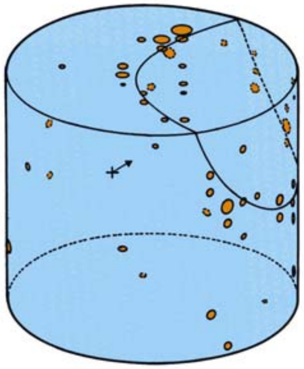
Supernova: 10^{44} J

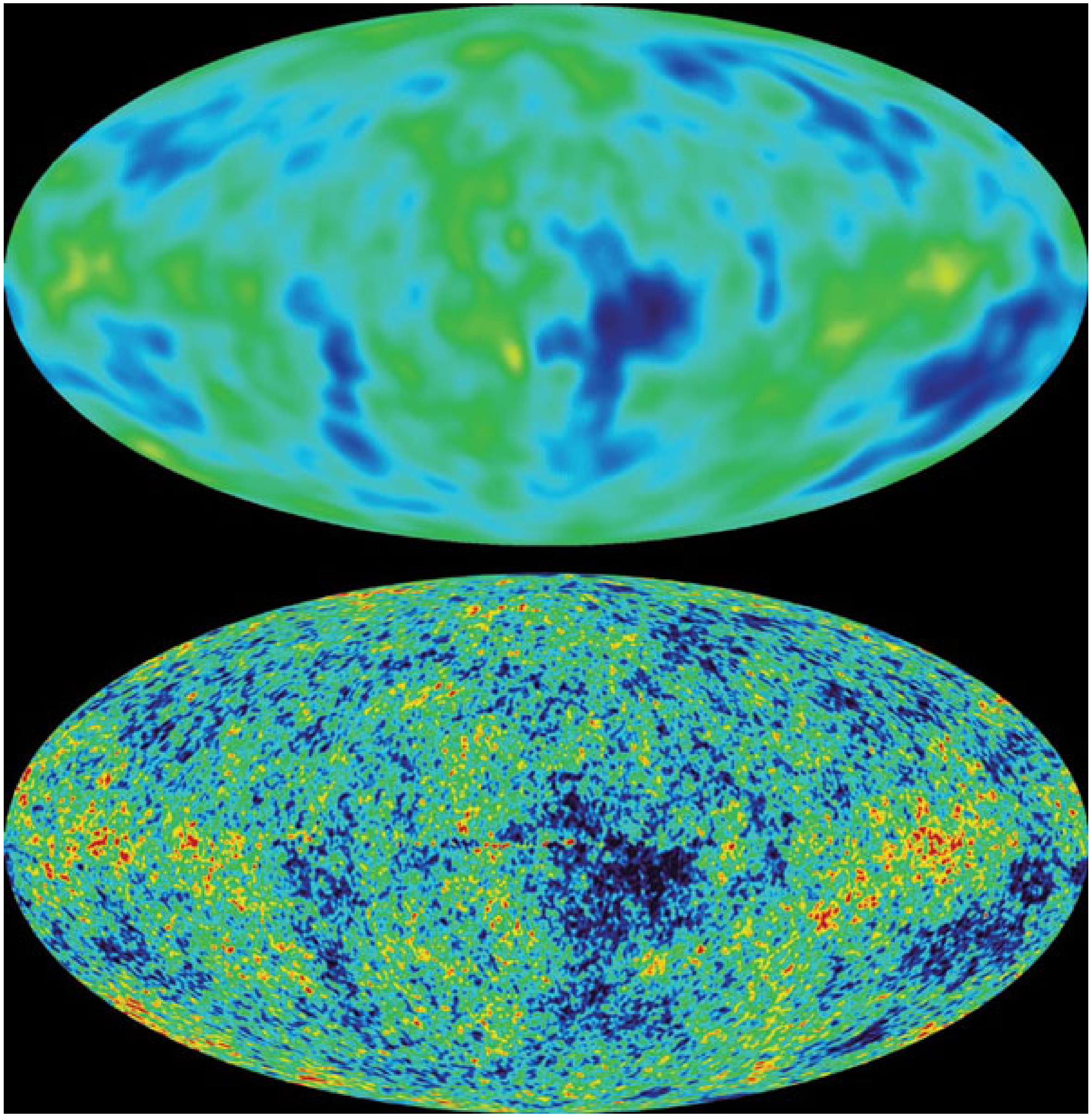


99% of energy released in the form of neutrinos.
In 1987, this supernova was detected by ~ 20 neutrinos
within 12 seconds on earth (160,000 light-years away).



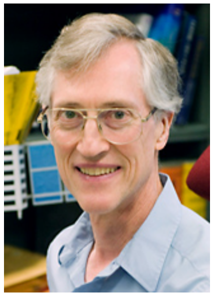


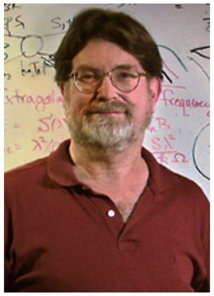


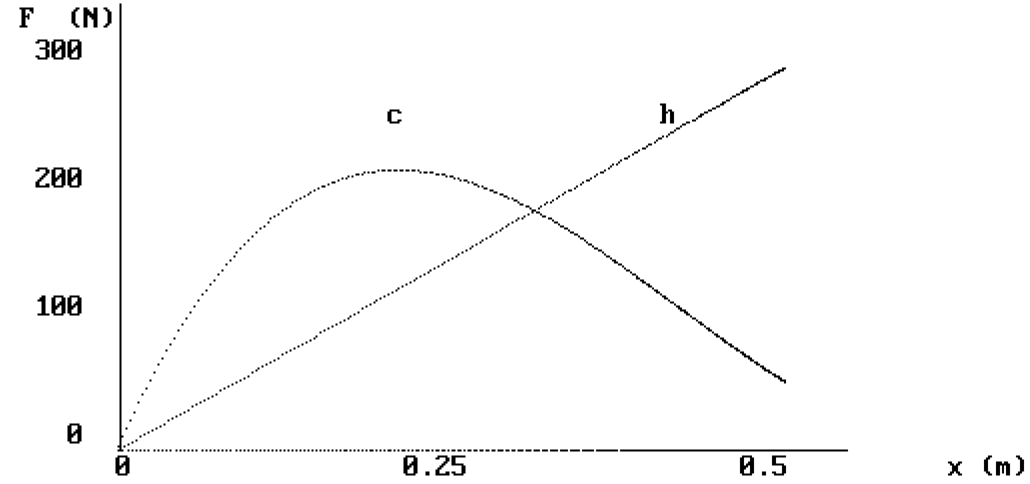


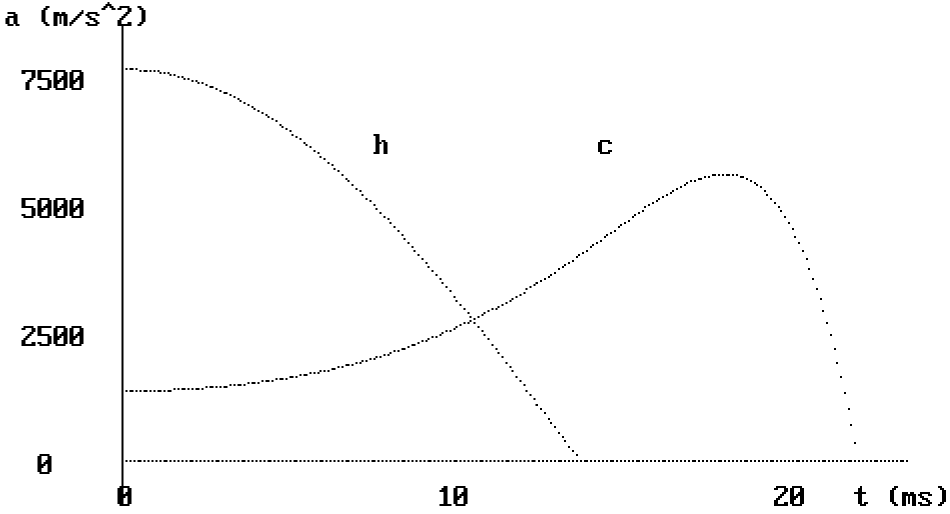
Creation of the Universe: 10^{68} J

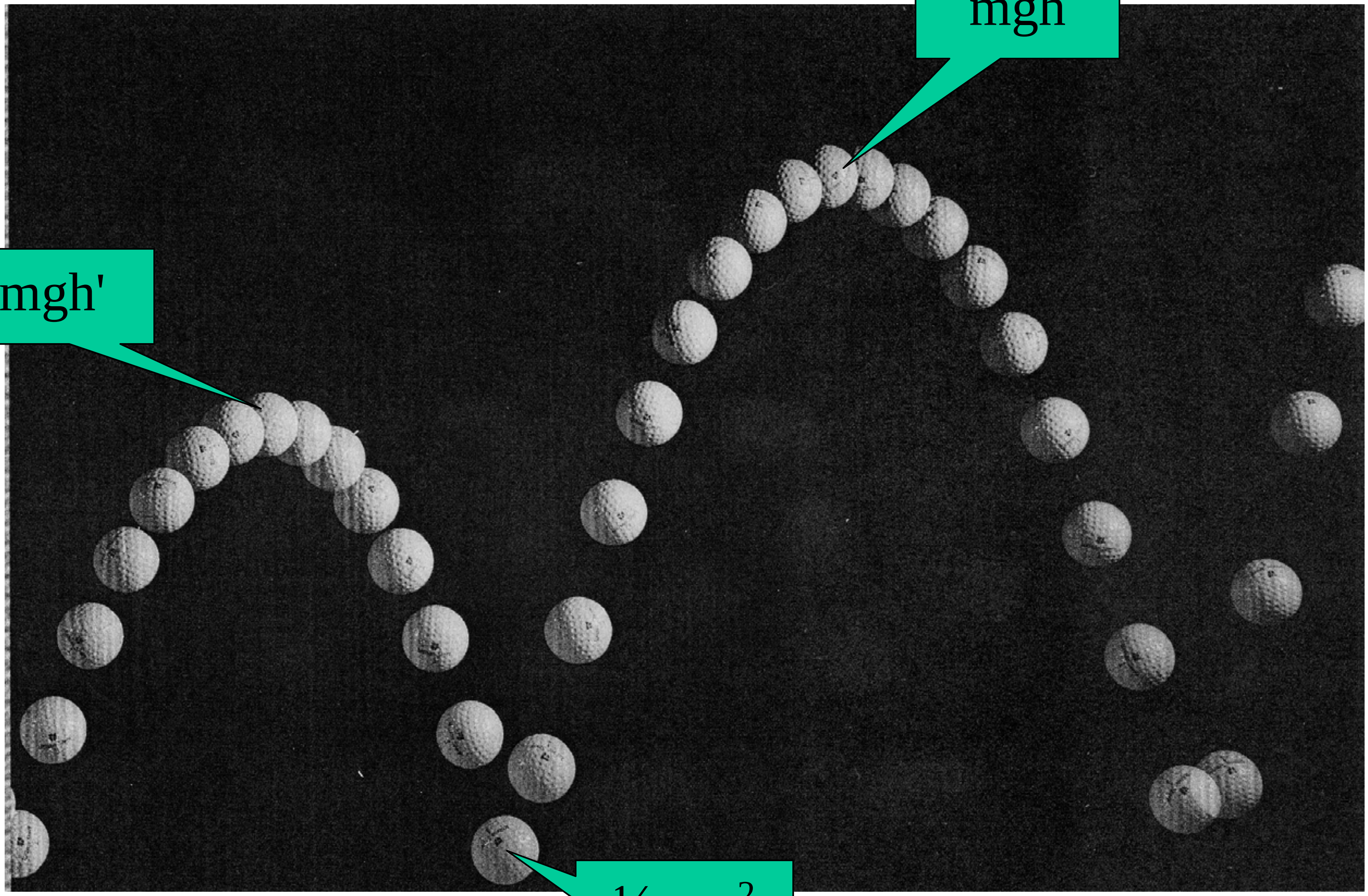
2006 Nobel Prize
in Physics






Comparison of Compound (c) and Hookeian (h) Bows
(Force versus Draw)

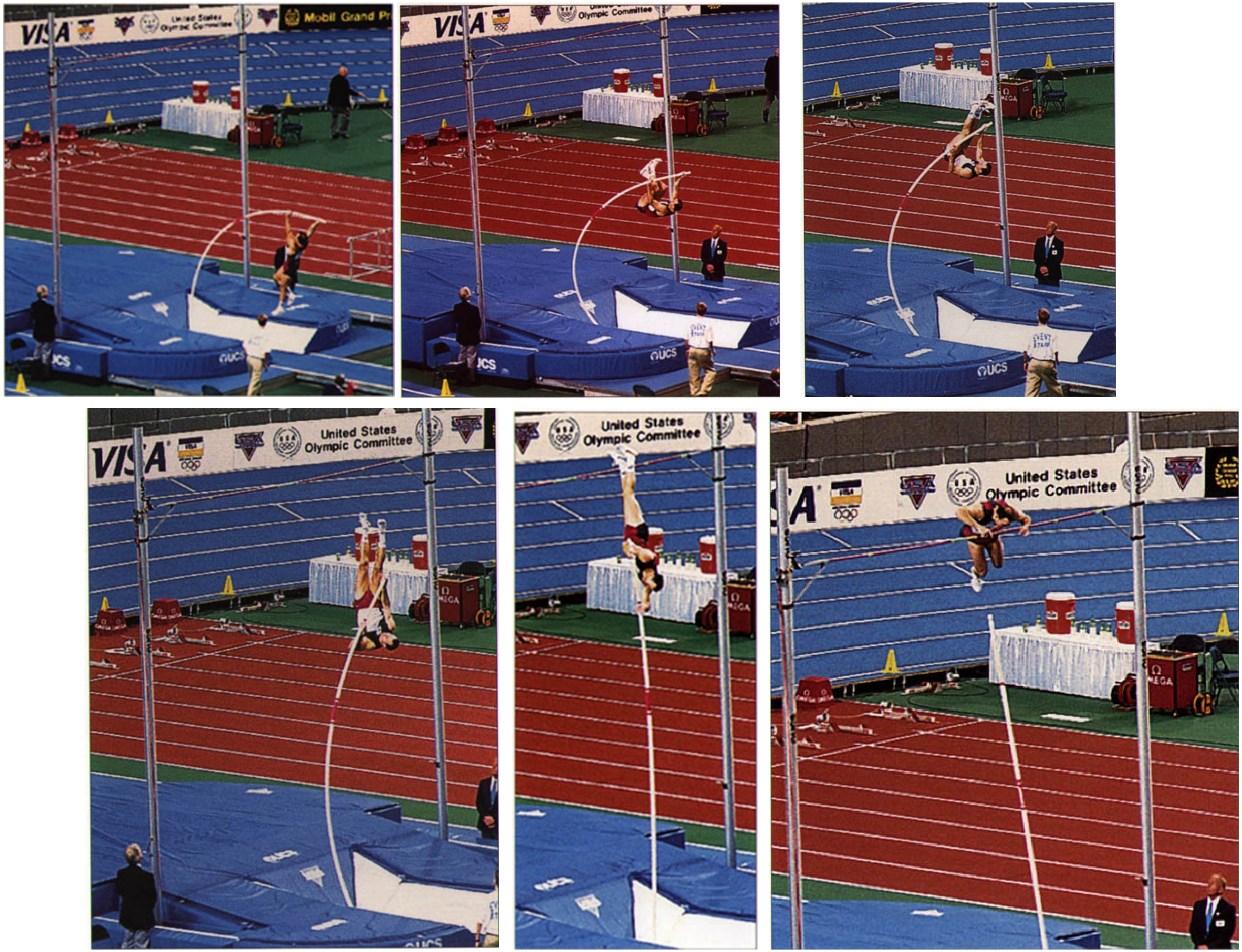

Comparison of Compound (c) and Hookeian (h) Bows
(Arrow Acceleration versus time during unload)

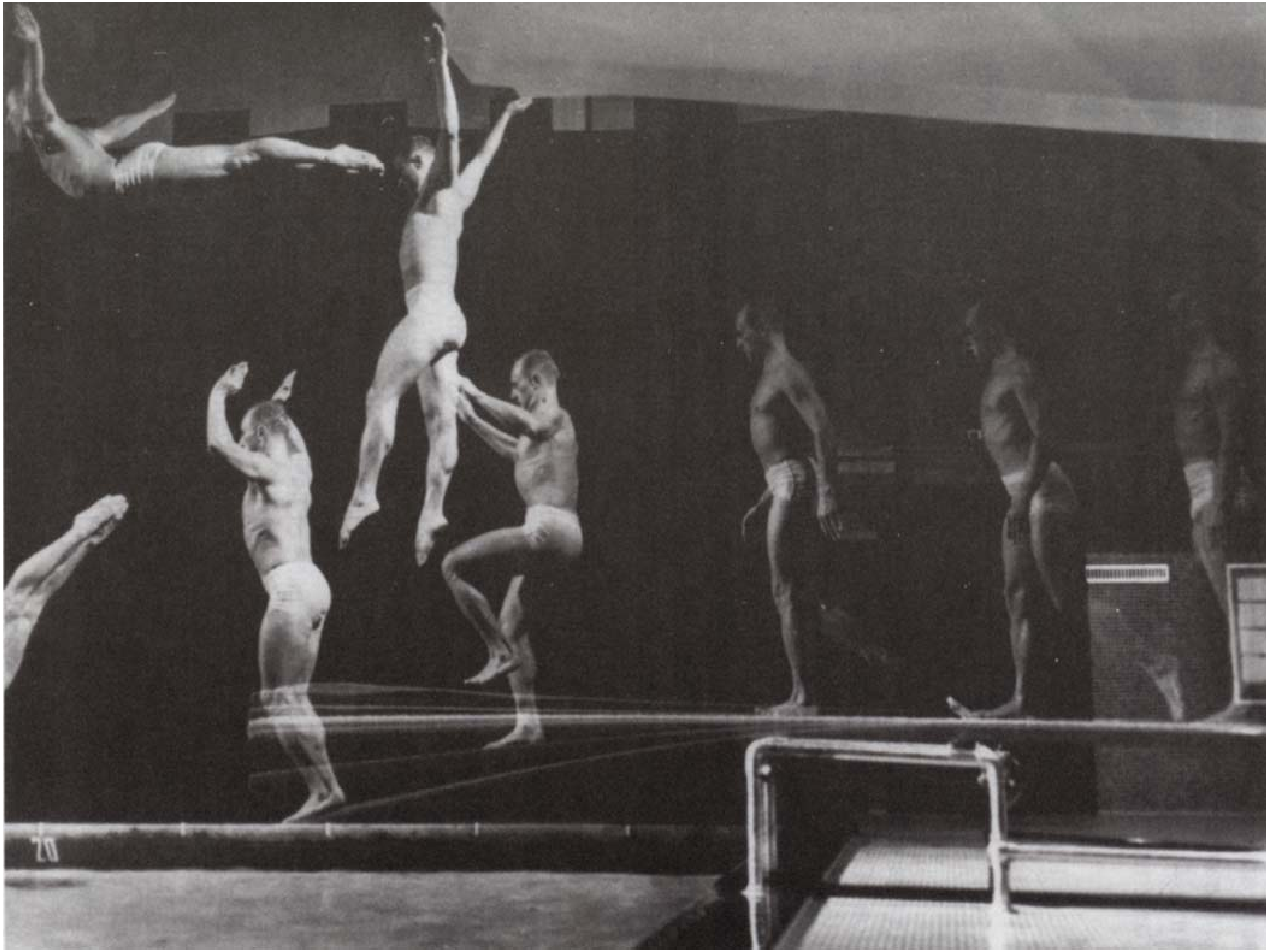


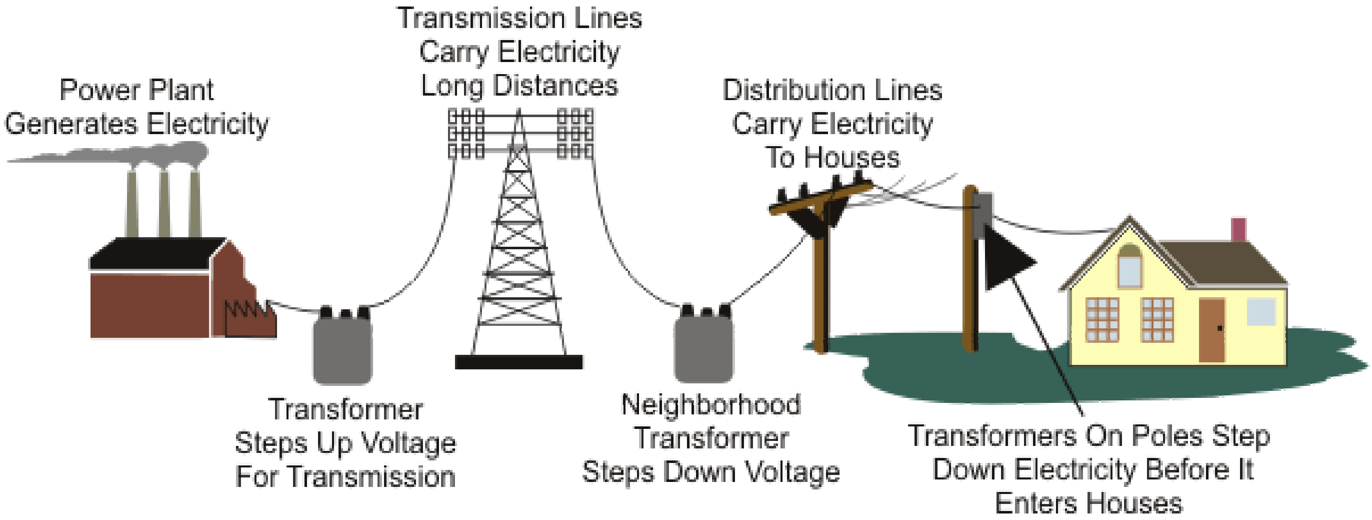
mgh

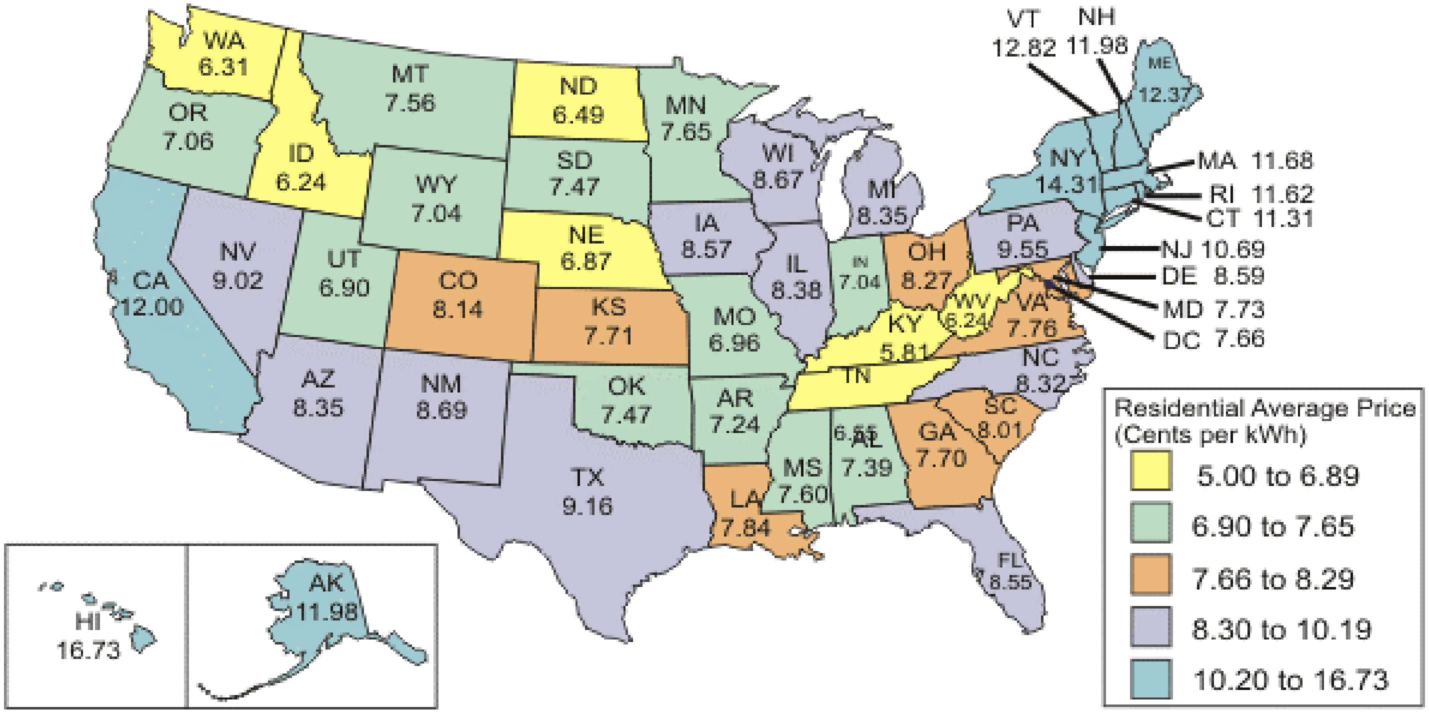
mgh'

$\frac{1}{2}mv^2$


VISA
United States Olympic Committee
Mobil Grand Pr
UCS
OMEGA
EVENT STAFF

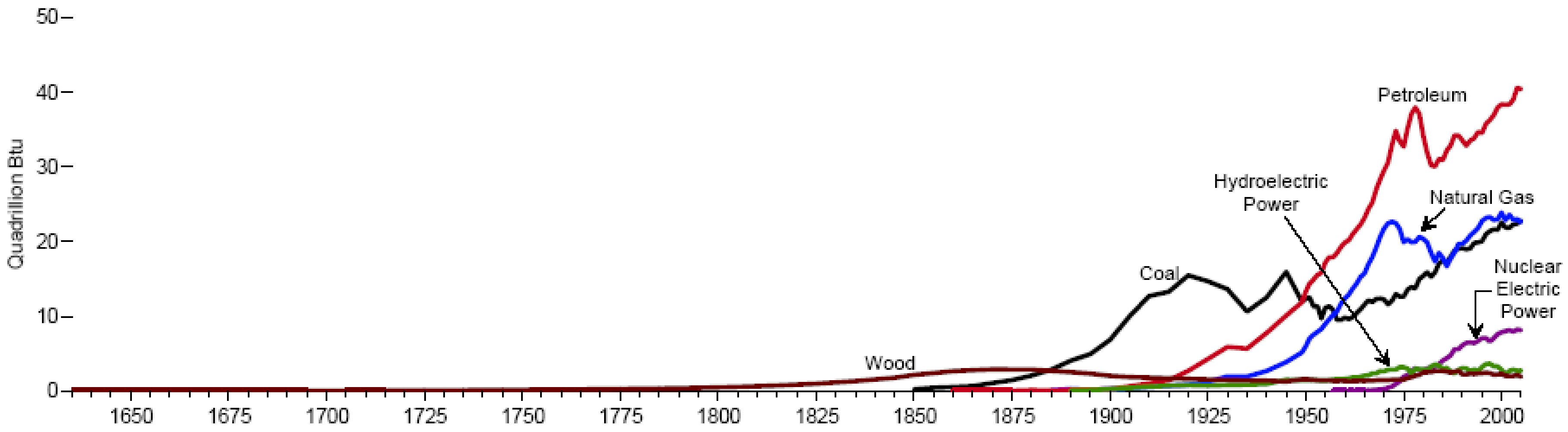

20

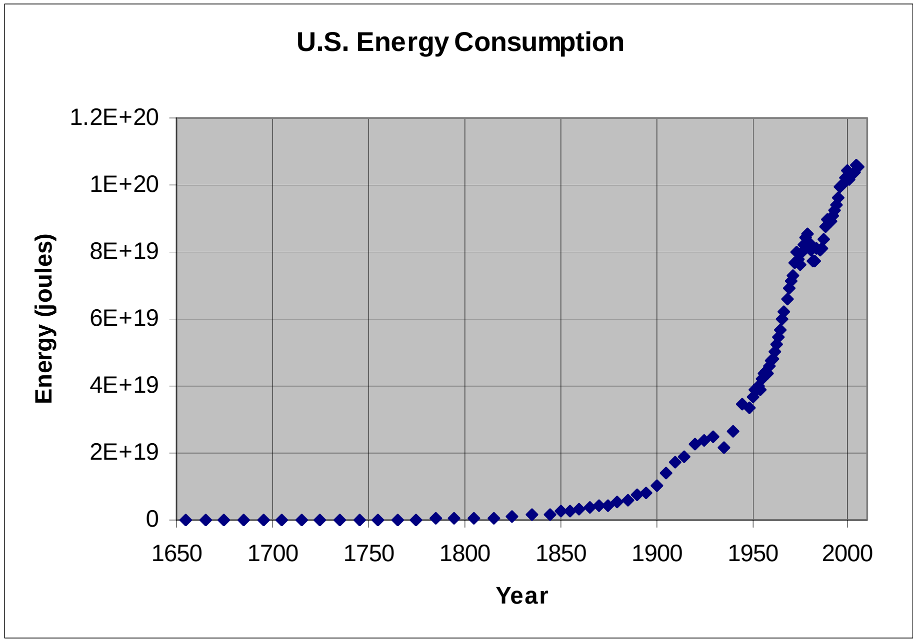


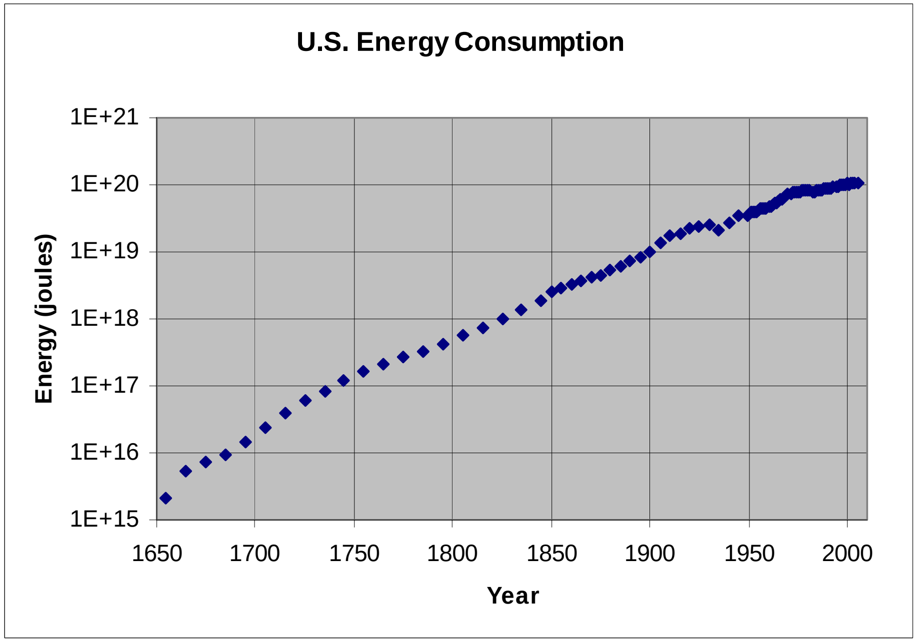


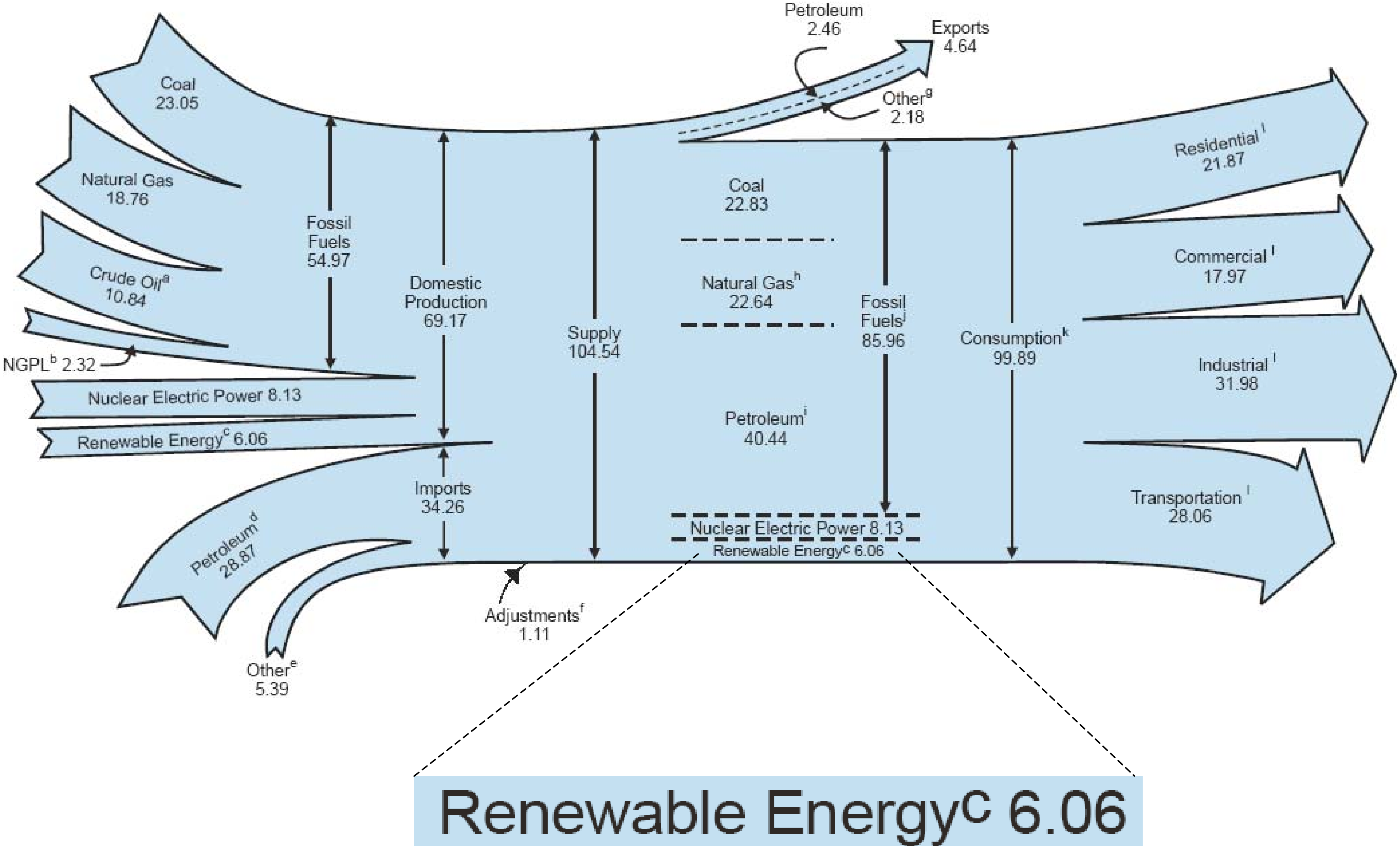
Source: Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

Figure 5. Energy Consumption by Source, 1635-2005








Coal 23.05
Natural Gas 18.76
Crude Oil[a] 10.84
NGPL[b] 2.32
Nuclear Electric Power 8.13
Renewable Energy[c] 6.06
Petroleum[d] 28.87
Other[e] 5.39
Fossil Fuels 54.97
Domestic Production 69.17
Imports 34.26
Adjustments[f] 1.11
Supply 104.54
Petroleum 2.46
Exports 4.64
Other[g] 2.18
Coal 22.83
Natural Gas[h] 22.64
Petroleum[i] 40.44
Fossil Fuels[j] 85.96
Nuclear Electric Power 8.13
Renewable Energy[c] 6.06
Consumption[k] 99.89
Residential[l] 21.87
Commercial[l] 17.97
Industrial[l] 31.98
Transportation[l] 28.06
Renewable Energy[c] 6.06

U.S. Total Energy Consumption Rate (10^{20} J / 3×10^{7} s)	3×10^{12} W
Hoover Dam	2×10^{9} W
Automobile at 60 mph	10^{5} W
Electric Stove	10 kW
Clothes Dryer	5 kW
Per capita electricity in US	1.5 kW
Solar intensity at earth, per square meter	1 kW
Desktop computer	200 W
100 W lightbulb	100 W
Laptop computer	40 W
Compact fluorescent lightbulb	18 W
Pocket calculator	10^{-3} W

TABLE 6.5 Human* Power and Oxygen Consumption

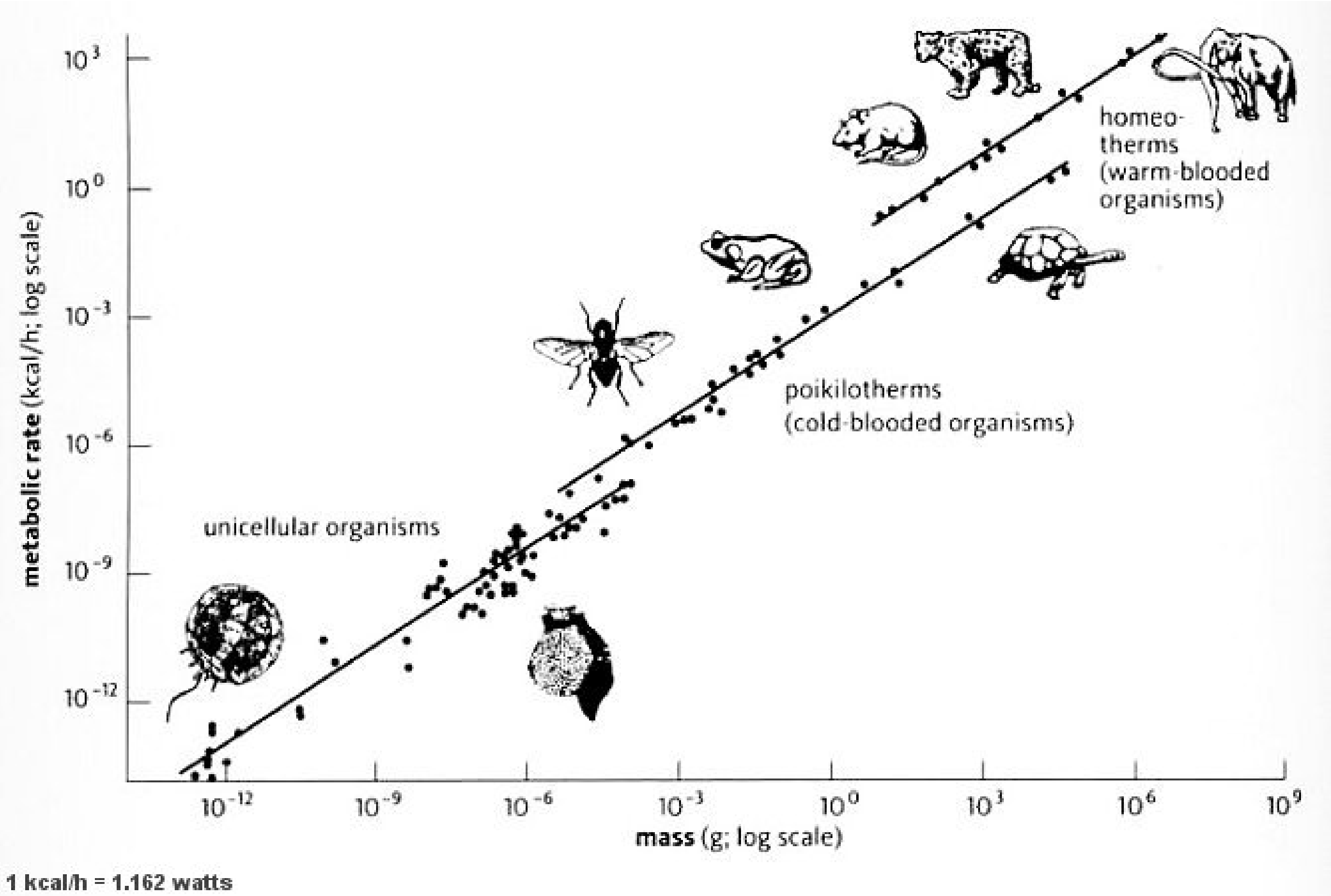
Activity	Power (watts)	Oxygen Consumption (liters 0_2/min)
Sleeping	83	0.24
Sitting at rest	120	0.34
Sitting in class	210	0.60
Walking slowly (4.8 km/h)	265	0.76
Cycling (13–18 km/h)	400	1.14
Shivering	425	1.21
Playing tennis	440	1.26
Swimming breaststroke	475	1.36
Climbing stairs (116/min)	685	1.96
Cycling (21 km/h)	700	2.00
Running cross-country	740	2.12
Playing basketball	800	2.28
Cycling, professional racer	1855	5.30
Sprinting	2415	6.90

*Normal 76-kg male.

TABLE 5.1

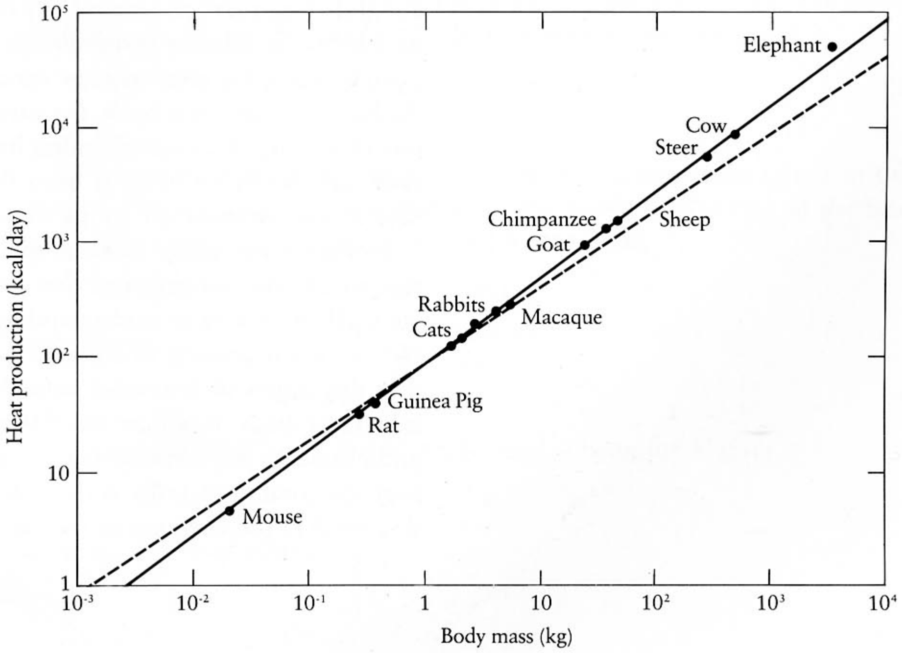
Maximum Power Output from Humans over Various Periods

Power	Time
2 hp, or 1 500 W	6 s
1 hp, or 750 W	60 s
0.35 hp, or 260 W	35 min
0.2 hp, or 150 W	5 h
0.1 hp, or 75 W (safe daily level)	8 h



Kleiber’s Law (1932)

Metabolic heat production vs. body mass in an allometric plot. The solid line has a slope of 0.75, as required by Kleiber's law. The broken line, which shows a slope of 0.67, has been included for comparison.



One simple line of reasoning using scaling:

Mass ~ Volume ~ L^3

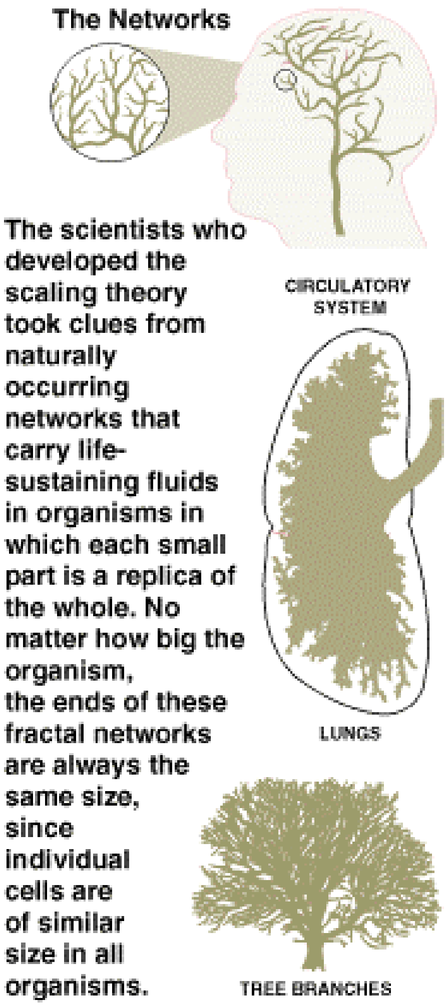
Equivalently L ~ $M^{1/3}$

Metabolic activity requires removal of Heat

Heat Dissipation ~ Surface Area ~ L^2 ~ $\mathbf{M^{2/3}}$ (dashed line)

But data seems to show $\mathbf{M^{3/4}}$ (solid line)

Some scientists suggest explanations for ¾ power…



The scientists who developed the scaling theory took clues from naturally occurring networks that carry life-sustaining fluids in organisms in which each small part is a replica of the whole. No matter how big the organism, the ends of these fractal networks are always the same size, since individual cells are of similar size in all organisms.

West, Brown, Enquist Science 276 (1977) p. 122

… other scientists suggest that it is 2/3 with more data and within statistical uncertainty

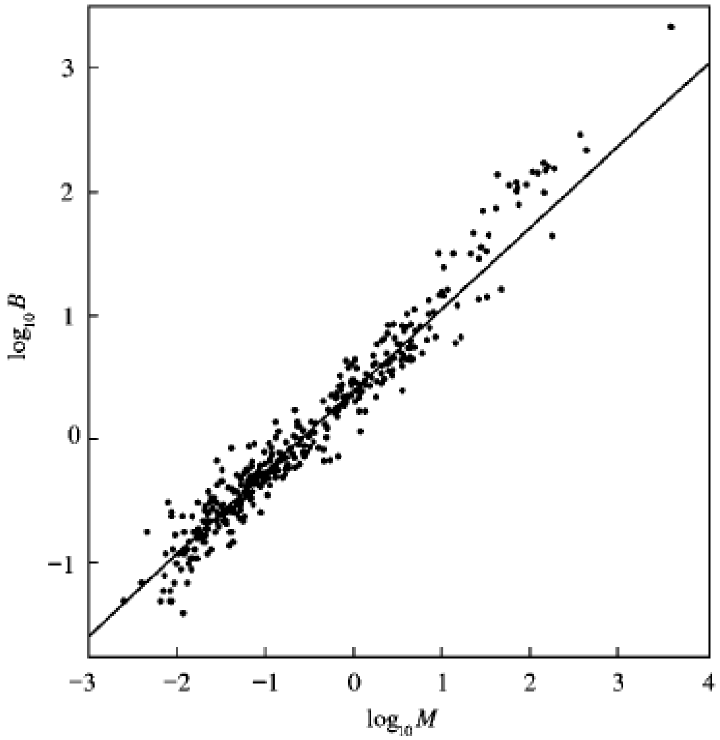


FIG. 1. Metabolic rate, B (watts), as a function of mass, M(kg), for 391 species of mammals. Data taken from Heusner (1991b). The straight line represents the best fit for the 357 species with mass less than 10 kg where $\hat{\alpha} = 0.668 \pm 0.019$. The upward deviations for species with larger mass (see Table 1) may indicate a real biological difference but may also be due to the paucity of data.

Dodds, Rothman, and Weitz, J. Theo. Biology 209 (2001) p. 9

Exploring Biomechanics Animals in Motion
R. McNeill Alexander
Scientific American Library

Measuring the oxygen consumption of a walking elephant: an experiment by a team led by Richard Taylor.