SI Units—Who Cares?
(Why Does It Matter?)

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OPCUG & PATACS

March 21, 2020

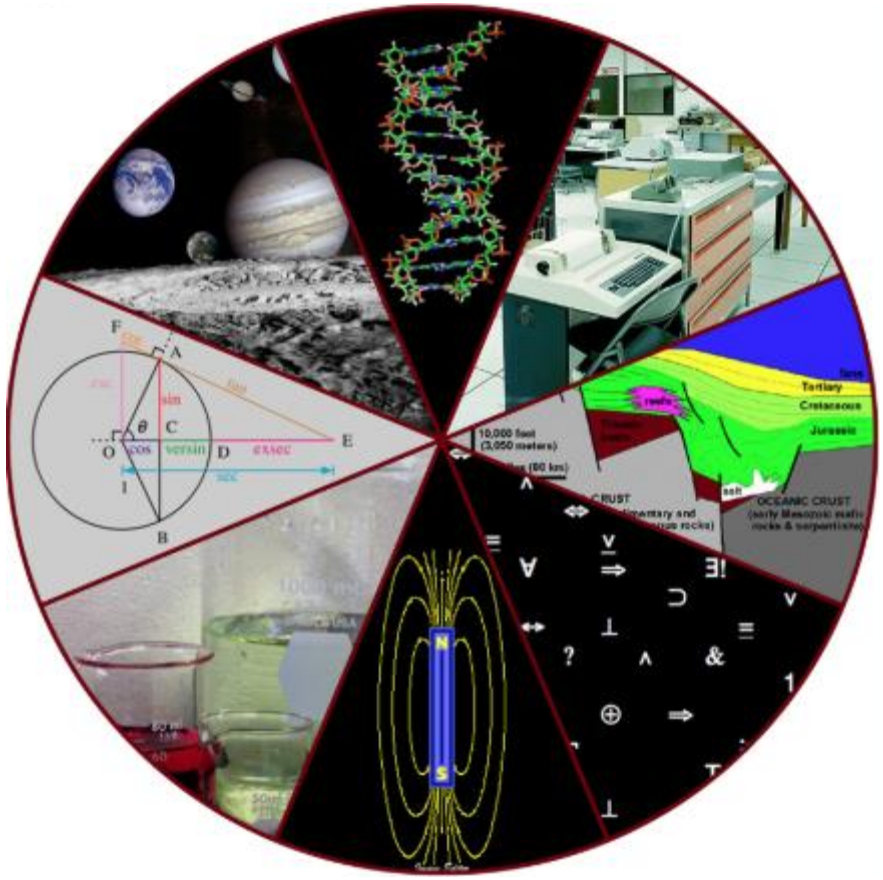
Being Forthright

- Information is presented at a “Dick & Jane” level of chemistry, physics and math
- Full understanding requires a grasp of quantum mechanics
- *Omitted details results in inaccurate statements*
- In-depth coverage requires a graduate level course in quantum physics or chemistry
- No condescension is intended

Imagine…

- If each city used a different measure of weight
- If every gas station had its own nozzle size or plug for charging electric vehicles
- If every lamp manufacturer had a different size bulb socket
- If every electrical appliance required a different voltage

The Sciences & Engineering Also Need Standards*



*** For both pure science and applications**

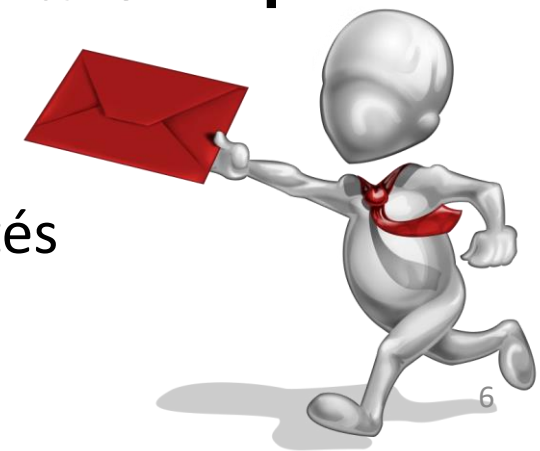
Why Are Standards Important?

- Standards facilitate innovation in commerce, communications, manufacturing, and science
- Standards have a profound direct and indirect impact on society
- Standards in the sciences—serve as a model
  - ✓ Standards are established and used internationally
  - ✓ BTW—English is the dominant international language of science and business. English is a standard

An Important Historical Event

- **May 20, 2019**
- The seven basic SI* standards were defined in terms of constants based on natural phenomena
- These seven standards are interrelated

Active link ↑



* SI comes from **S**ystème **I**nternational d'Unités aka **the metric system**


FREE PULLOUT
Daily Mail
70p
HOW TO MAKE A FORTUNE FROM YOUR HOME
PLUS: Win £10,000 tow
THIS PAPER IS WORTH 10 nectar POINTS
DOUBLE NECTAR POINTS ALL WEEK
Wow!
World Has Sensational New Standards!
STANDARDS
FAMILIES are still missing out on formal compensation for the contaminated blood scandal, campaigners warned last night.
By Ben Spencer
Medical Correspondent
Louis, up and running at Chelsea
MORE EN CHANTING PICTURES: PAGES 2-3

A Little History—Length

- 12th century: 1 foot = length of the foot of King Henry 1st of England

Note the king's flat feet ➔

- 14th century: 1 inch = length of three barleycorns, King Edward 2nd of England

Back to barlycorns and king's feet after BREXIT?

Weight

Our pound is derived from the Roman unit of weight, the libra

1 avoirdupois pound = 453.59237 g
0.45359237 kg

LiBra

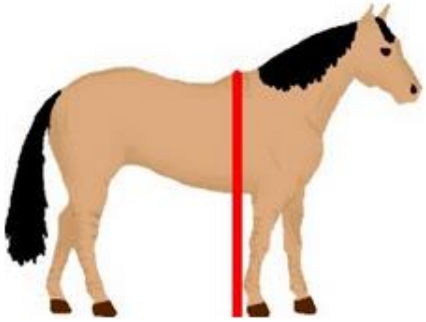
Difference Between Weight and Mass

Weight on the earth…
1 lb. or 0.453592 kg

Weight on the moon…
0.165 lb.

The mass of the cheese is 0.453592 kg anywhere
Weight is a function of gravity—mass is not

A Little Strangeness



Height of horses

1 hand = 4 in.

Weight of people in the UK

1 stone = 14 lbs.

Weight of diamond

1 carat = 0.2 g or 0.007 oz.

1 carat = 0.00705479239… oz

Three Systems of Measurement

- United States Customary Units
- Imperial System of Units
- International System of Units (SI)

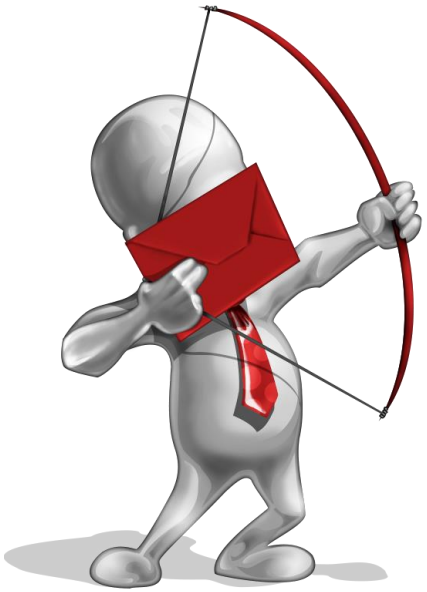
Who Uses What?

- United States Customary Units
  - ✓ United States
  - ✓ Canada (sort of) and the U.K (sort of)
  - ✓ Myanmar (formerly Burma)
  - ✓ Liberia
- International System of Units (SI)
  - Everybody else!

Detailed, authoritative information about SI Units

Who Uses What?

- Imperial System of Units
  - ✓ Mandated by the British Crown in 1824
  - ✓ Former British colonies
  - ✓ Little used



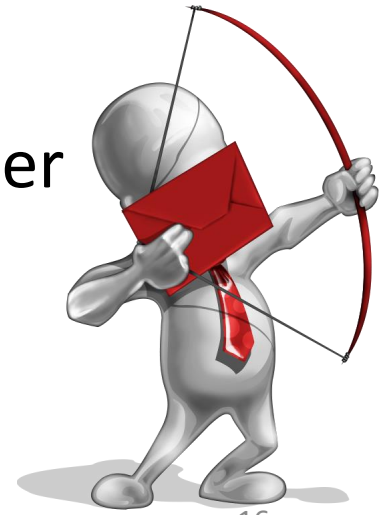
Use of the Metric System in the U.S.

- Virtually all the sciences
- Engineering (metric and U.S. Customary Units)
  - ✓ 1999: Loss of Mars orbiter ($125 million)
  - ✓ 1983: Air Canada flight ran out of fuel*
- Medicine
- U.S. military
- Some manufacturing

*Known as the “Gimli Glider”

The Mendenhall Order of 1893

- April 5, 1893. Thomas Mendenhall issued "Bulletin No. 26—Fundamental Standards of Length and Mass" (U.S. Coast and Geodetic Survey)
  - The avoirdupois pound was defined as 2.20462234 lbs. per kilogram
  - The yard was defined as 3600/3937 of a meter
    - ✓ 3600/3937 yard = 1.0000020002187 meter



What are the Seven Basic SI Units of Measurement?

1. Length (meter)
2. Time (second)
3. Mass (kilogram)
4. Temperature (°K)
5. Electric Current (ampere)
6. Luminosity (candela)
7. Mole (number of atoms)

Length—The Meter

- Symbol **m**
- 1793: 1/10,000,000 of the distance from the equator to the north pole through Paris
- Until May 20, 2019, the length of a Pt/Ir bar
- **The speed**
  299,792,45
- The meter
  vacuum in
- For more i

Time—The Second

- Symbol **S**
- When ^{133}Cs is bombarded by a laser, a single electron in the outer shell will cycle back and forth between two states*
- A second is defined as 9,192,631,770 cycles between these two states

* Known as hyperfine transition

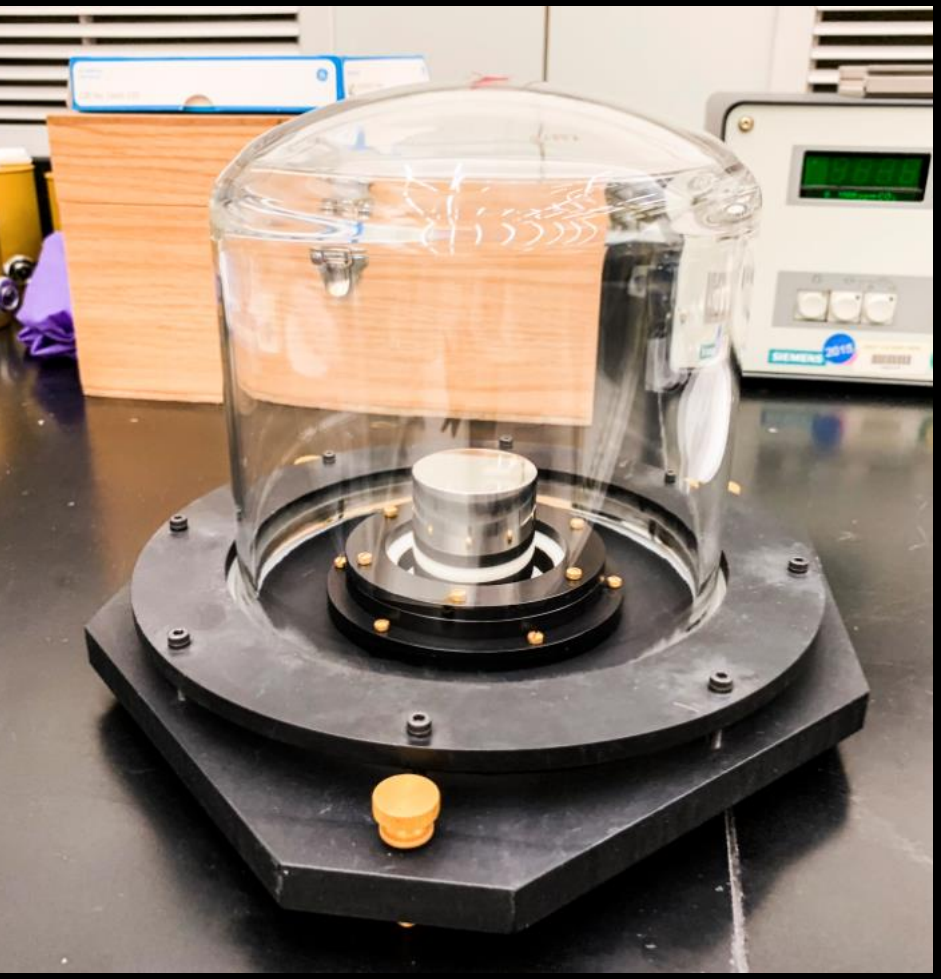
Time—The Second (cont.)

- What is a hyperfine transition?
- Think tuning fork…
- Accuracy of atomic clock
  ± 1 second in 300 million years*
- GPS (Navstar)—24 satellites with 4 atomic clocks in each satellite URL URL URL
- Position based on time it takes for signals to travel to the GPS
- For more information see URL URL

256 Hz
"C" note

* 300 million years = 9,467,280,000,000,000,000,000,000 seconds

U.S. Standard Kilogram Until May 20, 2019



The U.S. Kilogram

Patrick Abbott
"Keeper of the Kilo"

Mass—The Kilogram

- Symbol **kg**
- The kilogram is expressed in terms of Planck's constant (defined to have the exact value of $h = 6.62607015 \times 10^{-34}$ J.s)
- 1 joule (J) = 1/3600 of a watt-
- joule = kg.m^2/s^2 $E = mc^2$ (1 kg 4 J)
- Planck's constant describes th energy of a photon to its freq
- For more details see URL URL URL

0.000000000000000000000000000000662607015 J.s

Stephan Schlamminger's Left Arm

"Planck? Don't you mean plank?

"For all times, for all people"

Temperature—Kelvin

- Symbol **K**

Coldest attained temperature—He cooled to 0.0001 °K

- "Absolute Zero" aka "infinite cold"
- 0°K = –273.15 °C = –459.67 °F
- 72 °F = 22.22 °C = 295.37 °K
- Kelvin is defined in terms of the Boltzmann constant (1.380649×10^{-23} J/K) URL
- For more information see URL

Temperature—Kelvin (cont.)

↓ Pressure (atm)
↓ Volume (L)
↓ Temperature (°K)

$$PV = nRT$$ Ideal Gas Law

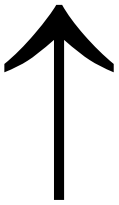
Mass (mol) ↑
↑ R = 0.082057366080960 atm-L/mol- °K

↓ Pressure (Pa)
↓ Volume (m^3)
↓ Temperature (°K)

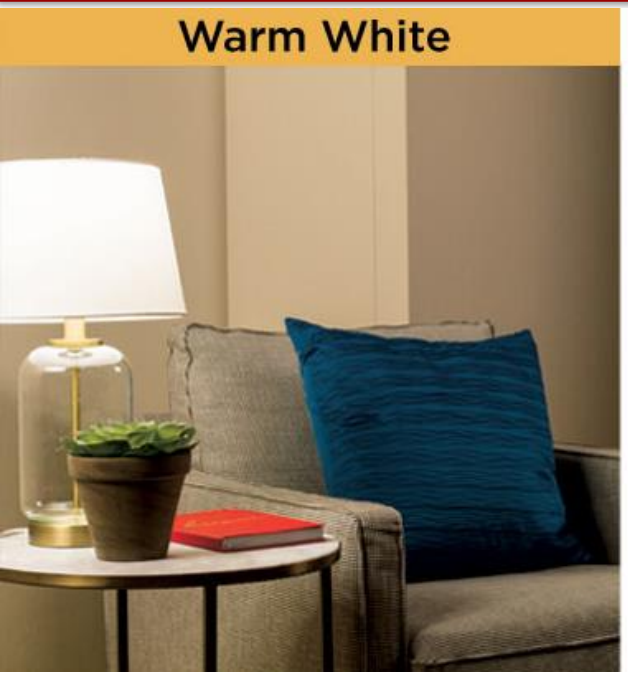
$$PV = NkT$$

Number atoms ↑
or molecules

Boltzmann constant

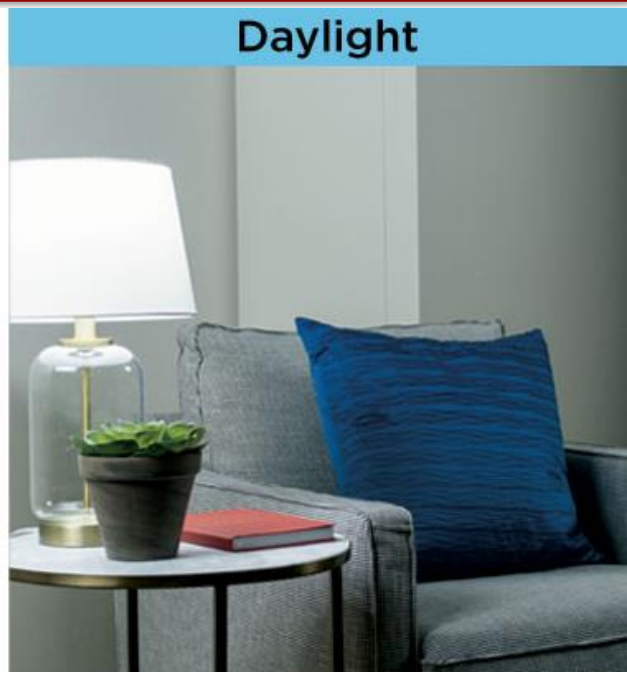


LED Light Bulbs and °K



2000K to 3000K

3100K to 4500K



4600K to 6500K

Electrical Current—The Ampere

- Symbol **A**
- The ampere is based on the amount of electric charge of a single electron (negative) or proton (positive) 

- The ampere is a measure of the amount of electric charge *in motion per unit time* — i.e., an electric current

Electrical Current—The Ampere (cont.)

- One ampere is the current in which one coulomb (symbol C) of charge travels across a given point in 1 second
- C = 6.241509074460762 x 10^{18} electron charges (e)*

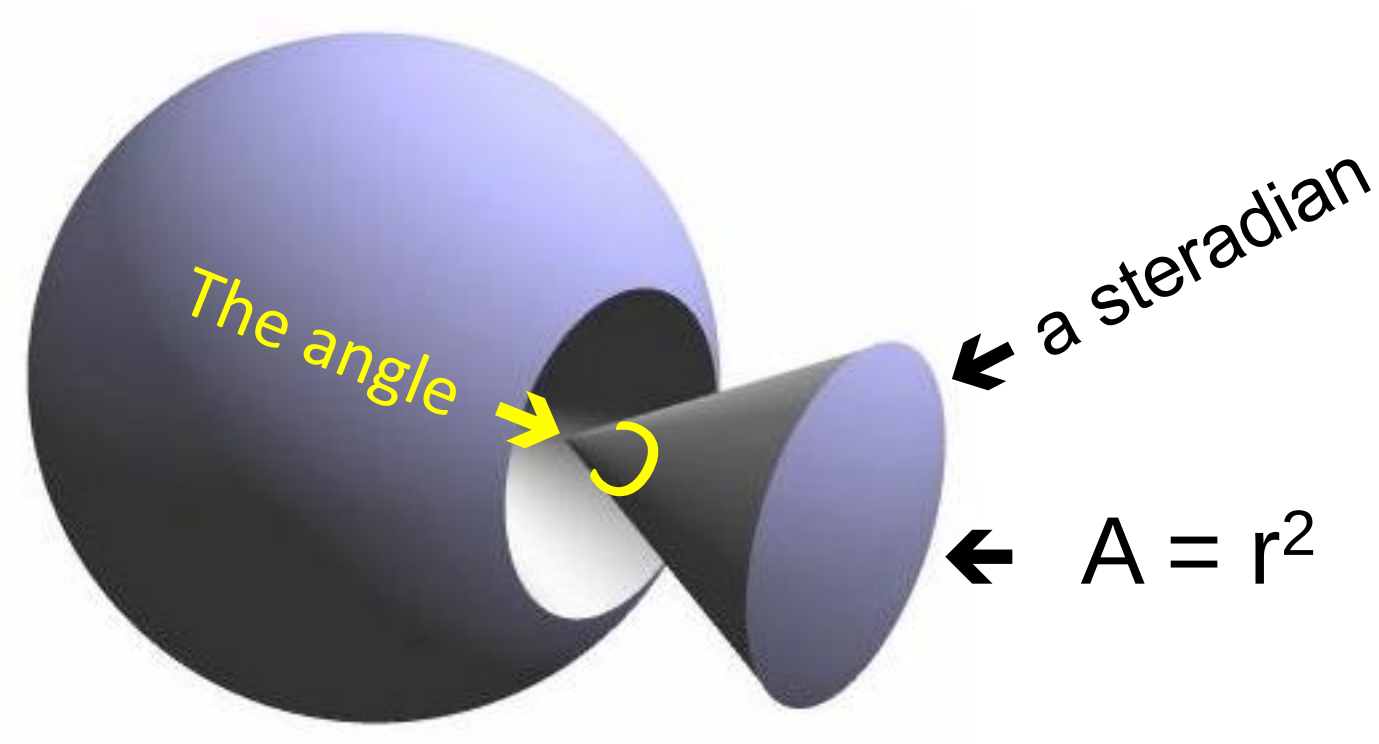
* 6,241,509,074,460,762,000 electron charges

Luminosity (Light)—Candela

- Symbol **cd**
- A common wax candle emits light with a luminous intensity of roughly one candela
- Light intensity is often expressed in lumens
- Lumen ≠ candela
- A lumen is equal to the amount of light emitted per second in a solid angle of one steradian from a uniform source of one candela  

A Steradian

A steradian is equal to the angle at the center of a sphere subtended by a part of the surface equal in area to the square of the radius



A sphere has 4 π steradians

Luminosity (Light)—Candela (cont.)

- "One candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian" 

- The candela is defined in terms of other basic standards (kilogram, meter, second)

Luminosity (Light)—Candela (cont.)

- At present the candela can only be measured to within one part in a thousand (0.1%)
- Improved measurement techniques will result into a more precise value for the candela

…but the phenomenon on which the candela is based remains constant

The Mole

The Mole—Amount of Substance

- Symbol **mol**
- **Old Definition:** amount of substance containing as many atoms or molecules as there are atoms in 0.012 kg of carbon-12
  - ✓Challenge: How do you determine the number atoms in 0.012 kg of ^{12}C?

Amount of Substance—The Mole (cont.)

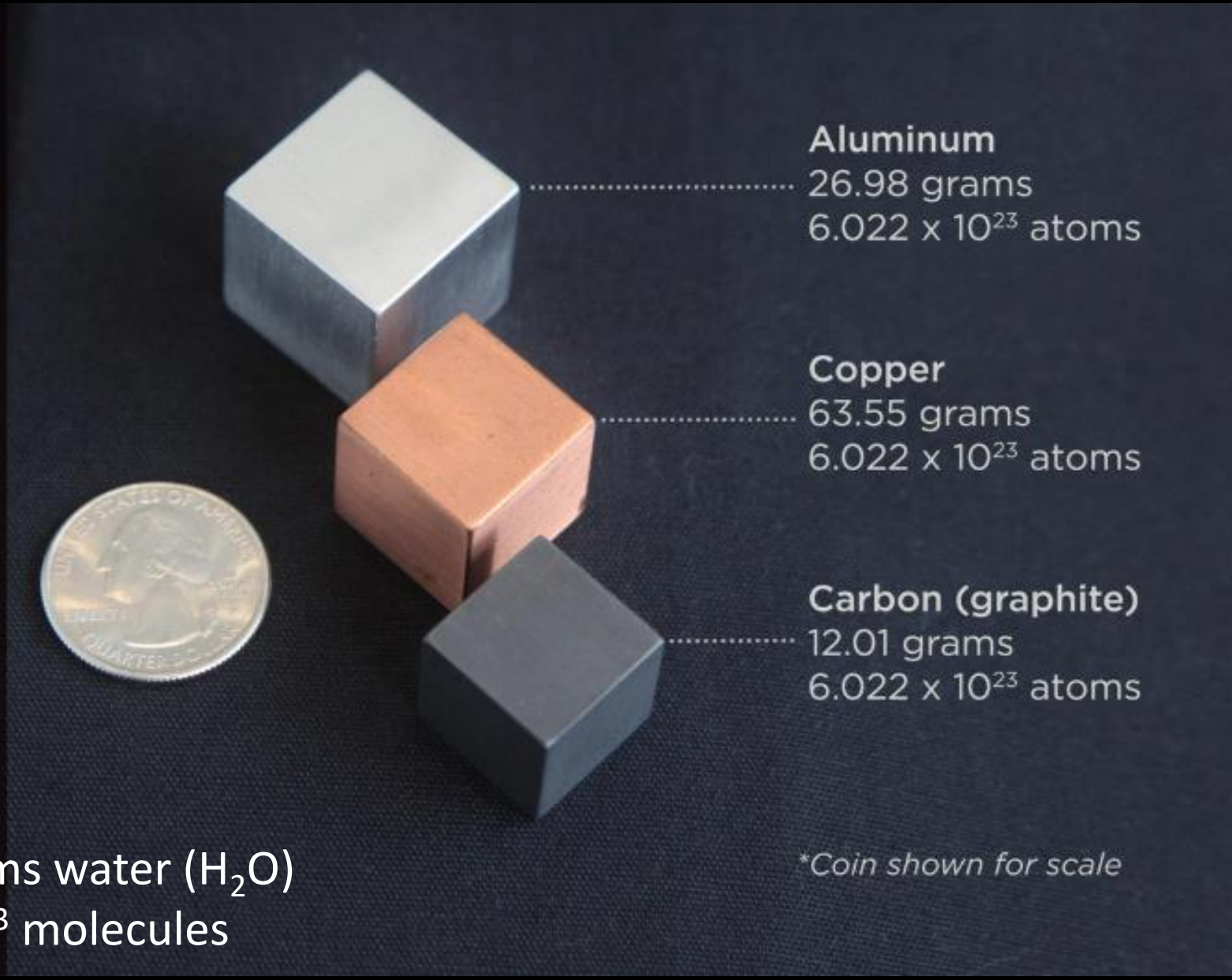
- Current standard based on Planck's constant
- The effort of several international groups working on a 1 kg sphere of ^{28}Si using…
  - ✓ Mass spectrometry
  - ✓ Interferometric measurements
  - ✓ X-ray crystallography

- Avogadro's Constant (N_A): $6.02214076 \times 10^{23}$ ($\pm 0.00000018 \times 10^{23}$) atoms or molecules/mole*
- References URL URL URL URL

$$V = \frac{4}{3}\pi r^3$$

* 1 mol ^{28}Si = 27.9769265325 g

18.015 grams water (H_2O)
6.022×10^{23} molecules



Additional References

- SI Units, basic information (a 4-minute video)
- Recommended CODATA values for physical constants*
- NIST: The International System of Units (SI) [2019]
- Wikipedia: 2019 Redefinition of the SI Base Units
- NIST: Redefining the World's Measurement System
- Some YouTube Videos:
  - ✓ New definitions for SI units
  - ✓ SI System | What Changes in 2019?
  - ✓ The kg is dead, long live the kg
  - ✓ Voting on the new SI Units

* 1,605 pp.

Thank You!