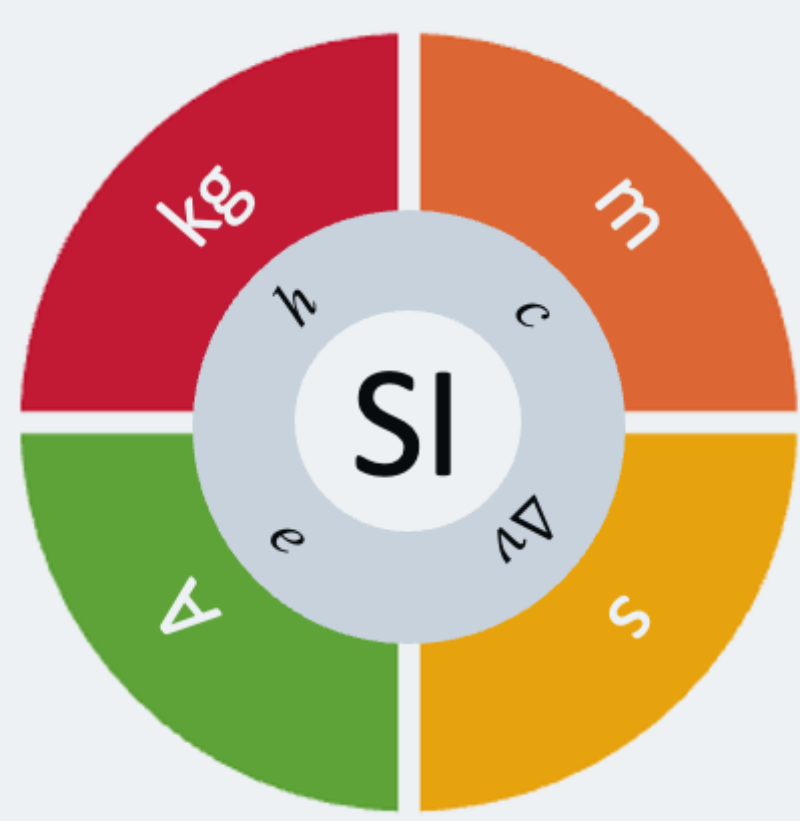




Does the International System of Units Lack Clarity? (and Can We Improve Our Understanding in the Next 50 Years?)



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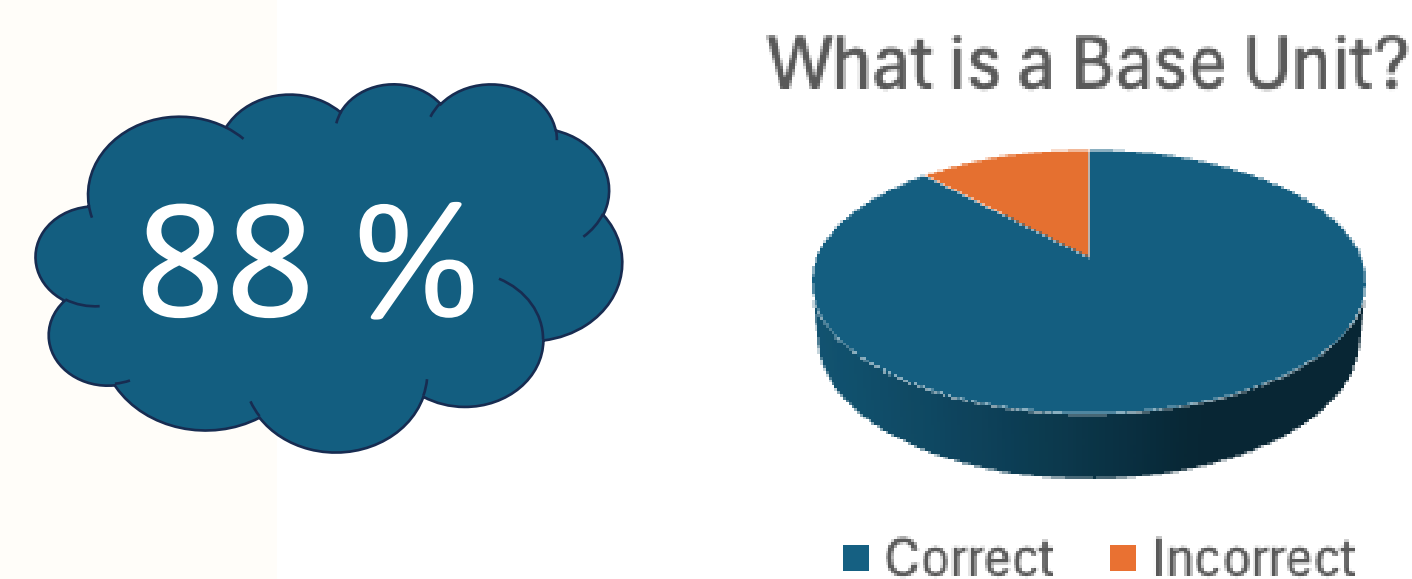
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The 2019 revision of the International System of Units (SI) established exact values for fundamental constants, thus enabling exact definitions, and to remain consistent with explicit descriptions of base and derived units in ISO80000. [1] [2] This revision has led some to question the relevance of the distinction between base and derived units. The SI's current set of seven "base" units, comprises two distinctly different subsets. The first comprises the kilogram (kg), meter (m), second (s), and ampere (A)—which together form a clear foundation of basic physics units upon which all other units can be formed. The second subset comprises the candela (cd), kelvin (K), and mole (mol) and has a very different character. Some might argue that the matter of clarity is subjective and lacks evidence. Furthermore, some will argue, there is no requirement that the SI be easy to understand, just as other aspects of science and engineering take years to master. We have undertaken a survey among STEM (Science, Technology, Engineering, Mathematics) university students, a small but important subset of aspiring custodians of the SI, to gauge their understanding and arguably the clarity of the SI.[3]

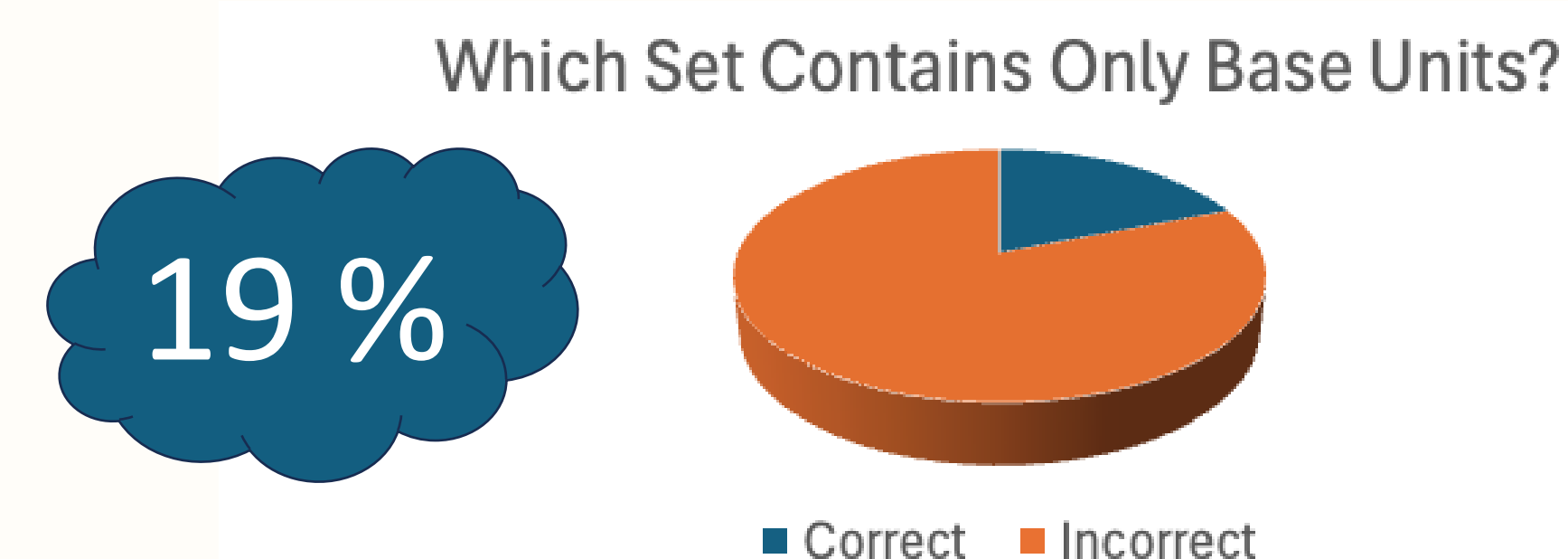
1) What is a base unit?

- a) Any unit of measurement
- b) A unit from which other units are derived
- c) A starting point for testing
- d) A unit of quantization



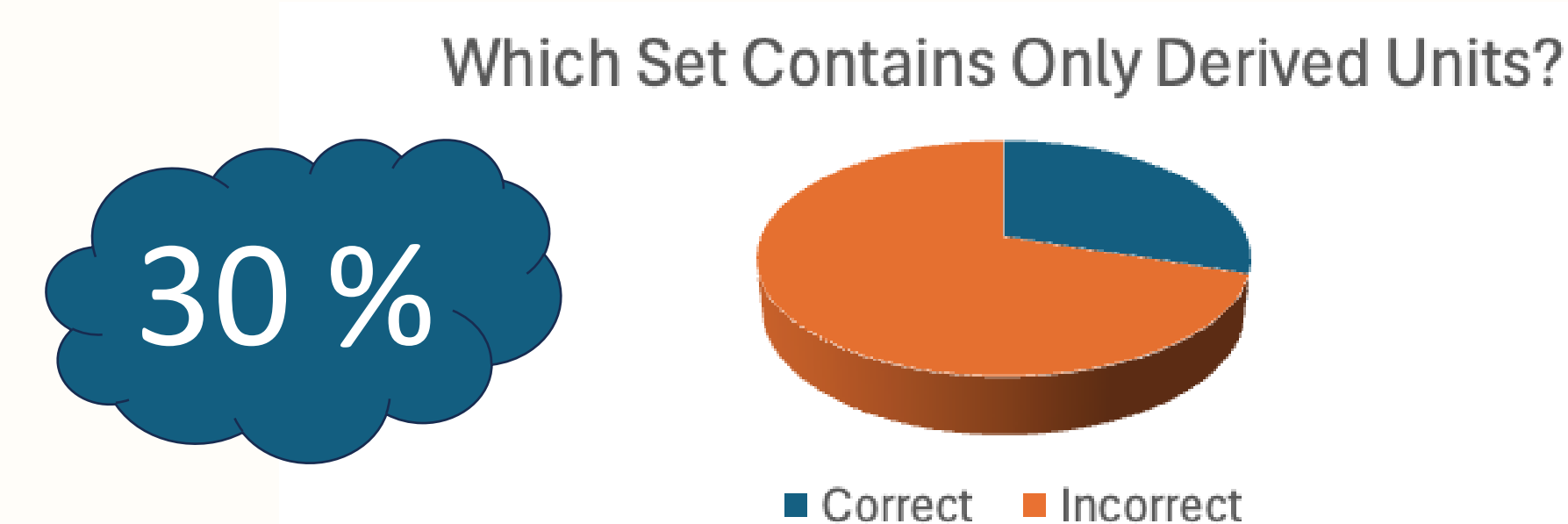
2) Which set contains only base units?

- a) kilogram, meter, joule
- b) coulomb, second, joule
- c) second, meter, coulomb
- d) kilogram, meter, ampere



3) Which set contains only derived units?

- a) volt, ampere, newton
- b) coulomb, joule, newton
- c) kilogram, meter, ampere
- d) second, newton, joule



Sampling and Method:

Third- and fourth-year STEM undergraduates, 75 students, anonymous

Ideas:

- There is no requirement that the SI be easy to understand.
- Is it misunderstood because it's complicated, not properly taught, unclear or improperly organized?
- Maybe it doesn't matter: bridges get built, medicine gets made, rockets launch.

A list of basic and derived SI units and related operational definitions

Unit Category	Measured Quantity	Name of Unit	Symbol	Dimensionality of Unit						SI Unit Powers	Operational Definitions
				M	L	T	I	∠			
Base Units	Physical	mass (M)	kilogram	kg	1	0	0	0	0	kg	Sizes of these four base units were adjusted to agree with the SI-defined exact values for the natural constants h , c , Δ_{cs} , e
		length (L)	meter	m	0	1	0	0	0	m	
		time (T)	second	s	0	0	1	0	0	s	
		current (I)	ampere	A	0	0	0	1	0	A	
	Angular	angle (A)	radian	rad	0	0	0	0	1	rad	
		solid angle (A)	steradian	sr	0	0	0	0	2	sr	
Derived Units		area	sq. meter	m ²	0	2	0	0	0	m ²	A measure whereby a right angle comprises $\pi/2$ rad
		volume	cu. meter	m ³	0	3	0	0	0	m ³	A measure whereby a cube corner comprises $\pi/2$ sr
		velocity		v	0	1	-1	0	0	m s ⁻¹	Area of a surface of a square with a 1 m edge
		acceleration		a	0	1	-2	0	0	m s ⁻²	Volume of a cube with a 1 m edge
		ang. frequency		ω	0	0	-1	0	1	s ⁻¹ rad ⁻¹	Rate of change of position of 1 m per s
		ang. acceleration		$\dot{\omega}$	0	0	-2	0	1	s ⁻² rad ⁻²	Rate of change of velocity of 1 m per s, per s
		charge	coulomb	C	0	0	1	1	0	s ⁻¹ A ¹	Rate of change of angle of 1 rad per s
		force	newton	N	1	1	-2	0	0	kg m s ⁻²	Angular velocity increase rate of 1 rad per s, per s
		energy	joule	J	1	2	-2	0	0	N m	Charge transferred by 1 A in 1 s
		power	watt	W	1	2	-3	0	0	J s ⁻¹	Force causing a mass of 1 kg to accelerate at 1 m/s (1)
		electric potential	volt	V	1	2	-1	-1	0	J C ⁻¹	Work by a 1 N force over 1 m of parallel motion
		resistance	ohm	Ω	1	2	-2	0	0	V A ⁻¹	Energy transfer rate of 1 J per s
Combined Derived Units		electric field		V/m	1	1	-3	1	0	V m ⁻¹	Electric potential energy per unit of charge
		magnetic flux	weber	T	1	-2	0	-1	0	VA ⁻¹ m ⁻¹	Electric potential difference per unit of current
		capacitance	farad	F	-1	-2	4	2	0	CV ⁻¹	Electric force per unit of charge
		inductance	henry	H	1	2	-3	-2	0	VA ⁻¹ s	Flux change rate of one weber/s induces 1 volt per turn (2)
		radiant intensity		W/sr	1	0	-3	0	0	W sr ⁻¹	Charge displacement per potential difference (3)
		irradiance		W/st m ²	1	0	-3	0	-2	W s ⁻³	Radiant power of 1 W per sr
		radiance		Nm	1	3	-2	0	-1	W sr ⁻¹	Radiant power of 1 W per m ²
		torque		K	1	3	-2	0	0	W rad ⁻¹	Radiant power of 1 W per m ² per sr
Scale Spanning Units	absolute temperature	kelvin	K	0	0	0	0	0	0	J	Rate of change of potential energy 1 J per rad
	quantity of matter	mole	mol	1	2	-3	0	0	0	W	Energy divided by k_B (5)
Additional Derived Units	amount of 540 THz light	lumen	lm	1	2	-3	0	0	0	lm	Amount of matter comprising N_A similar particles (5)
	luminous flux	lux	lx	1	0	-3	0	0	0	lm m ⁻²	Power of light at frequency 5.4×10^{14} Hz times K_{cd} (5)
	illuminance	candela	cd	1	2	-3	0	-2	0	lm sr ⁻¹	Photopic-weighted broadband luminous flux
	luminous intensity	nit	nt	1	0	-3	-2	0	0	lm m ⁻² sr ⁻¹	Luminous flux per area

(1) This definition avoids the need for a coefficient in the equation $F=ma$, which is convenient.
(2) This definition avoids the need for a coefficient in the Lorentz force law, which is convenient.
(3) This definition avoids the need for a coefficient in the equation for the charge on a capacitor, which is convenient.
(4) This definition avoids the need for a coefficient in the equation for the rate of change of current in an inductor.
(5) The special coefficients are: $k_B \approx 1.38 \times 10^{-23}$ J/K $N_A \approx 6.02 \times 10^{23}$ $K_{cd} = 6.83 \times 10^2$ lm/W.

Suggested for Clarity

C, N, J, W, V, Ω , T, f, H...	K, cd, mol
derived units	scale-spanning units
kg, m, s, A	
SI base units	

1. BIPM, *The International System of Units (SI)*, 9th edition (2019), <https://www.bipm.org/en/publications/si-brochure>
2. ISO 80000-1:2022(en) Quantities and units, <https://www.iso.org/obp/ui/es/#iso:std:iso:80000:-1:ed-2:v1:en>
3. N. Finkelstein, L. Whitehead, The 2019 SI Revision Has Not Lessened the Importance of the Base/Derived Unit Distinction, In Press, *European Journal of Physics*, (2025).