Goodbye, Mr. kilogram !

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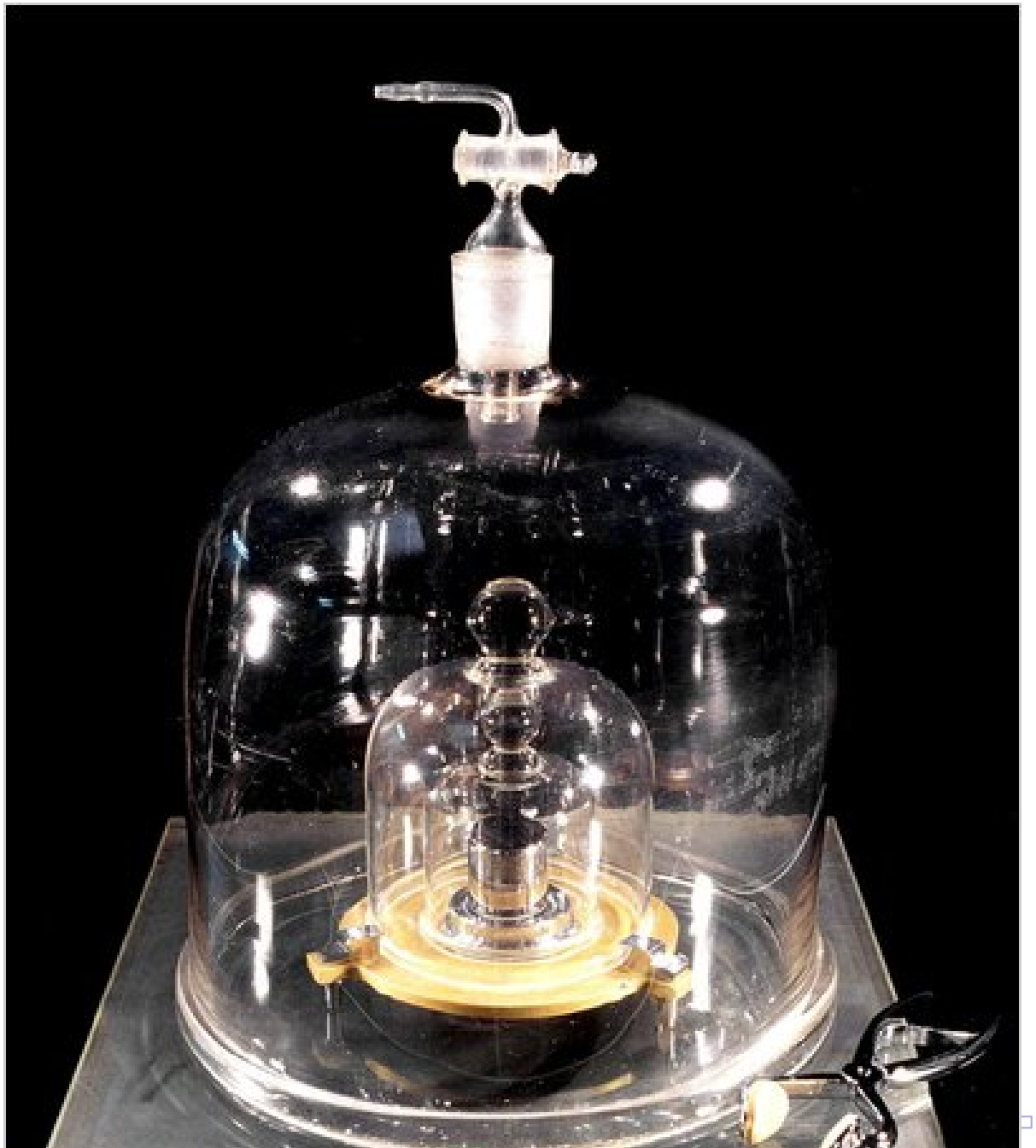
The International Prototype Kilogram (IPK)



Problems with a physical object as standard

- A small accident would change everything !
- Inconvenient and undemocratic !
- Since 1889, mass has changed by 50 μg !

But what is the alternative ?

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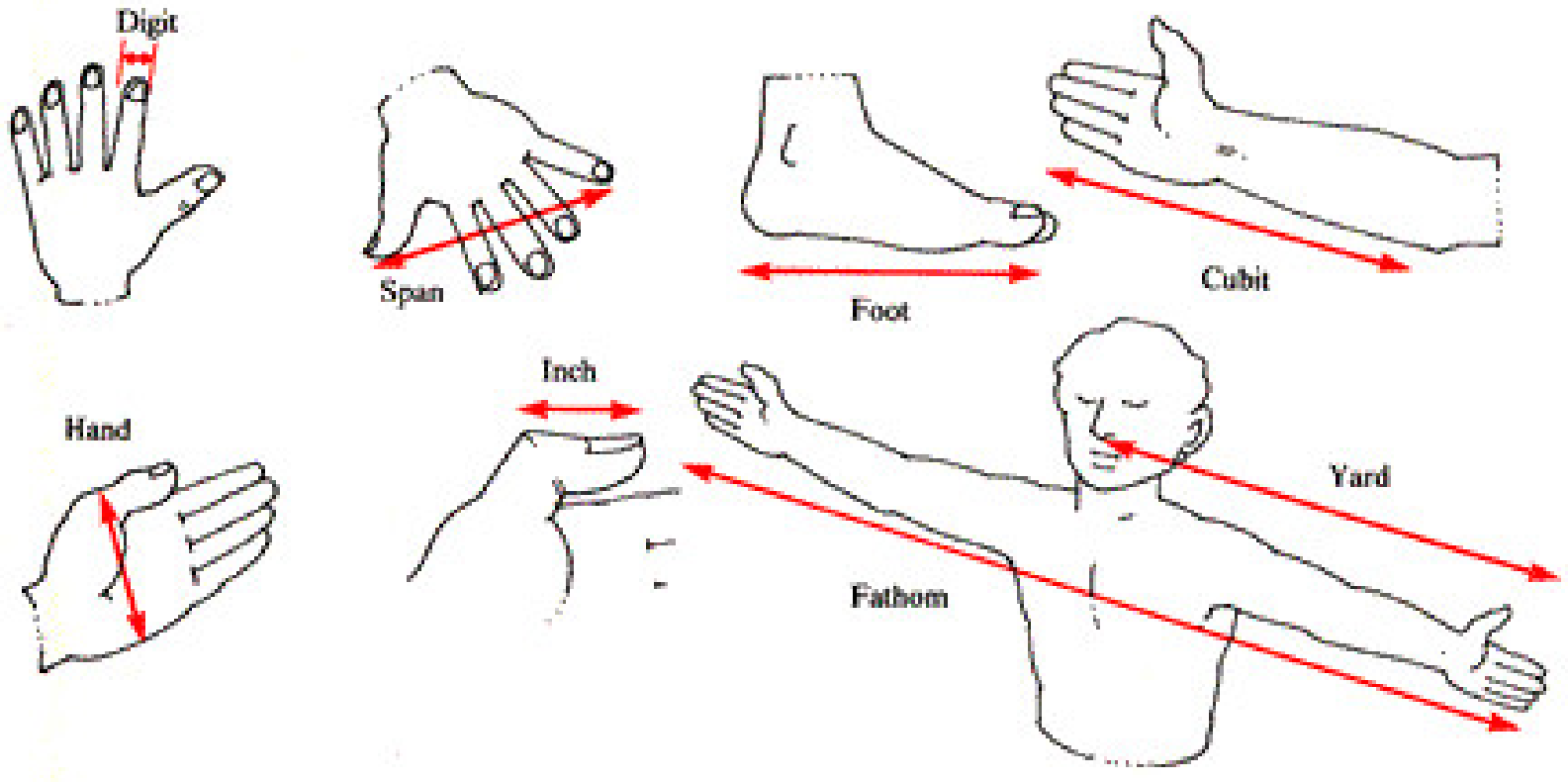
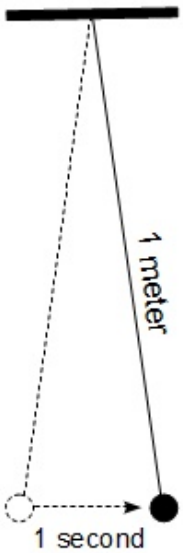
Length units

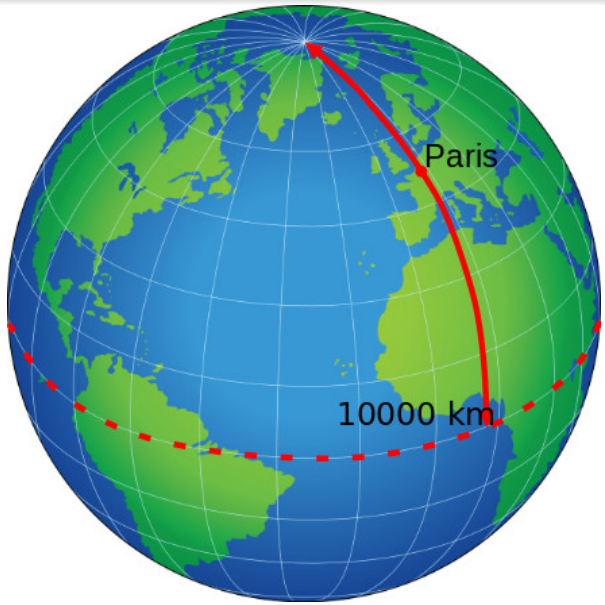


The definitions of metre

Pendulum-based (pre-French revolution)

- Length of a seconds' pendulum (half-period of a second)
- Varies from place to place





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- 1/10,000,000 th of a half-meridian
- 1799: "metre de Archives"
- Accuracy of 0.1 mm

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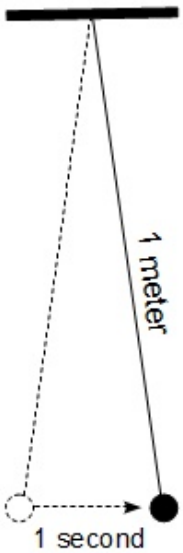

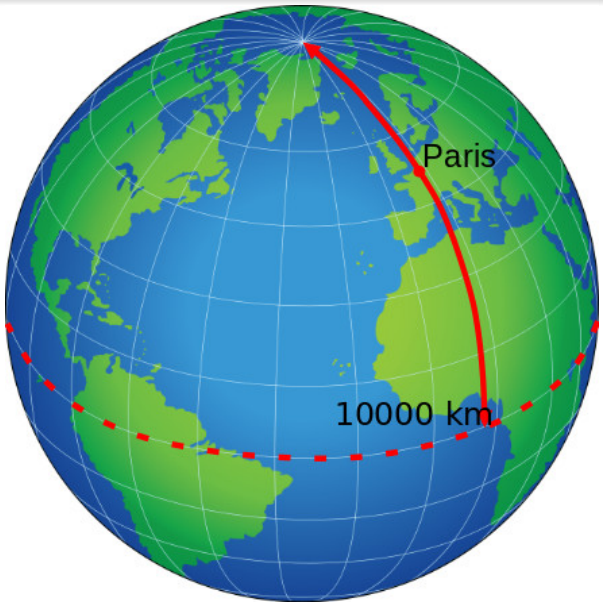

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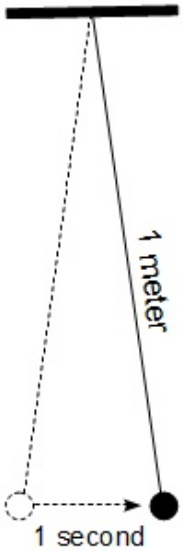

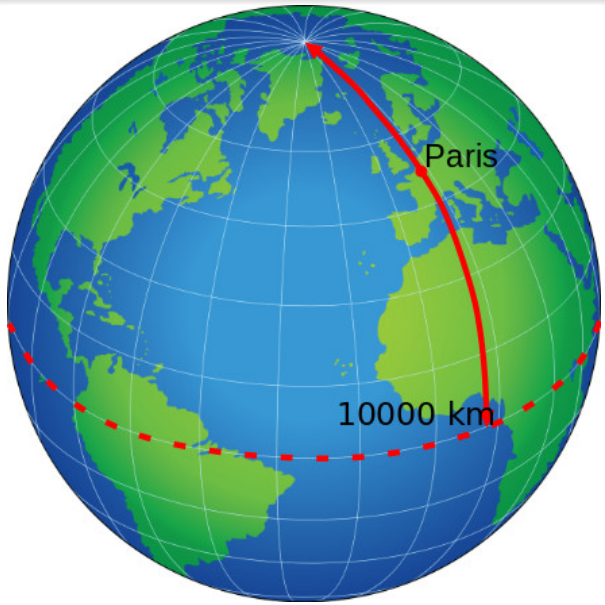

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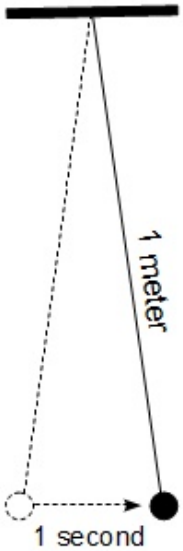

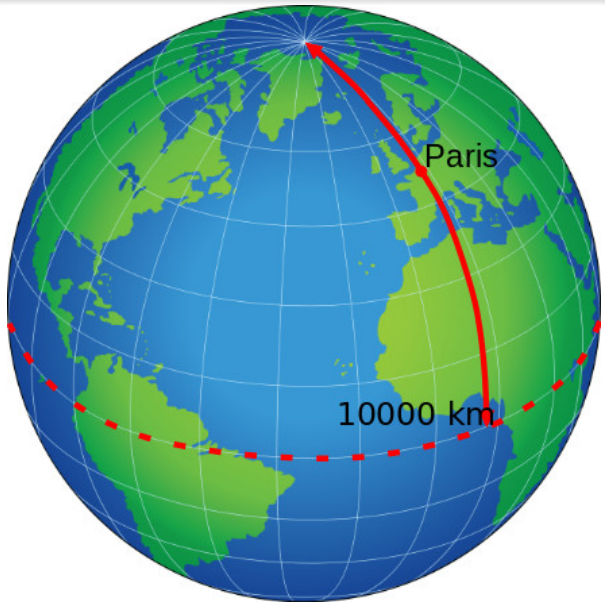

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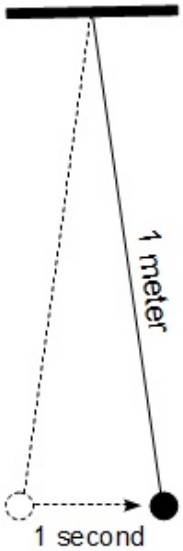

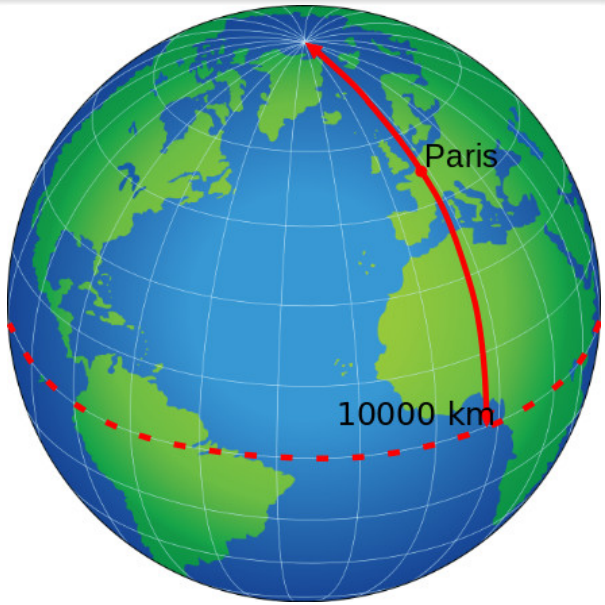

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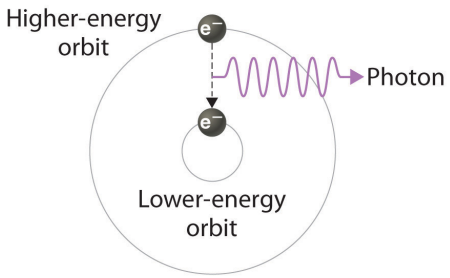
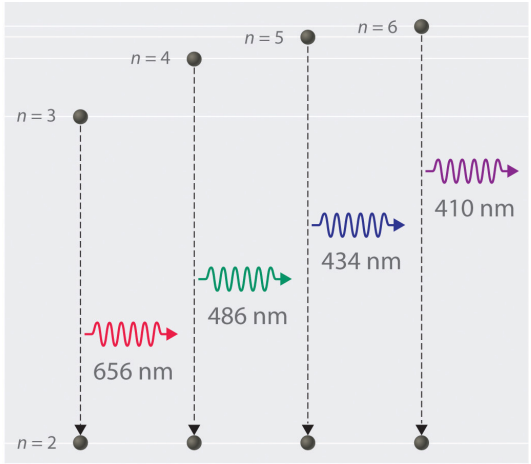
International prototype metre (1889 – 1960)

- Platinum $\rightarrow$ Platinum-Iridium
- 1927 definition: 0° temperature, one standard atmospheric pressure, supported by 2 cylinders at 571 cm separation
- Accuracy: 2 μm

Quantum Mechanics makes things more accurate...



(a) Electronic emission transition



(b) Balmer series transitions

Based on krypton line (1960 – 1983)

- 1,650,763.73 wavelengths of light from a specified transition in krypton-86 ($2p_{10} \rightarrow 5d_5$)
- Accuracy: 0.01 μm
- Kr line found to be asymmetrical when compared with more accurate lines

Special Relativity relates distance and time...

Based on the speed of light (1983 –)

- Distance travelled by light in a vacuum in 1/299,792,458 th of a second

Back to distance in terms of time ? (remember pendulum)

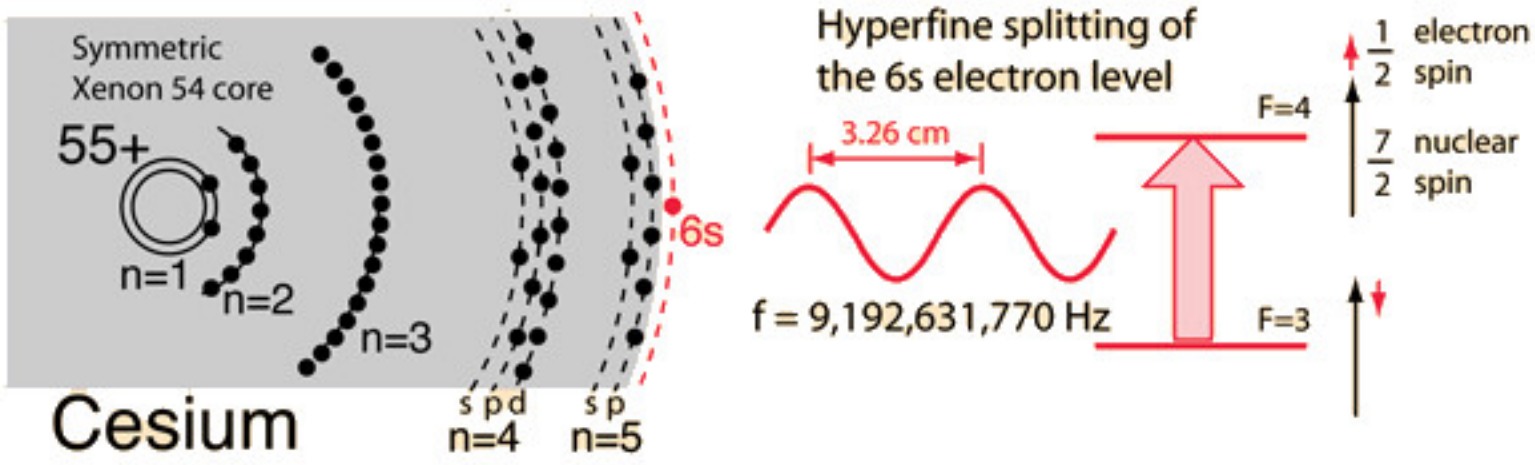
Advantages

- No dependence on source
- Special Relativity checked by multitude of experiments
- Speed of light in vacuum is a fundamental constant of nature !
- The measure of time accurate to 13 decimal places known...

Changing definition of time

day-based

- 1/86400 of a mean day



Atomic transition-based

- 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
- At the mean sea level (General relativity !)

The principle behind accurate definition of a metre

- Choose definition of time based on a very accurate measurement (selected from nature)
- Choose a fundamental constant of nature that connects time and distance
- Measure the fundamental constant as accurately as possible, and freeze its value
- Through this fundamental constant, define a metre.
- This definition will now last forever...

Back to kilogram

Fundamental constants needed

- Fundamental constants should connect mass with distance and time
- Planck's constant connects energy and time $E = h \times f$
- Special relativity connects rest mass and energy $E = mc^2$
- $m = hf/c^2 = (h/c^2)/T$
- A combination of Planck's constant and speed of light OK

Definition of a kilogram

- Planck's constant $h = 6.626070040 \times 10^{-34}$ J-s
- One kg is that mass, whose rest-mass energy would be equal to that of light with frequency $1/6.626070040 \times 10^{34}$ Hz

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Could we have done this...

100 years ago ?

- Special relativity just getting established
- No Quantum mechanics
- General relativity just proposed

10 years ago ?

- Watt balance idea was developed
- Needed Josephson junction effect and Quantum Hall effect

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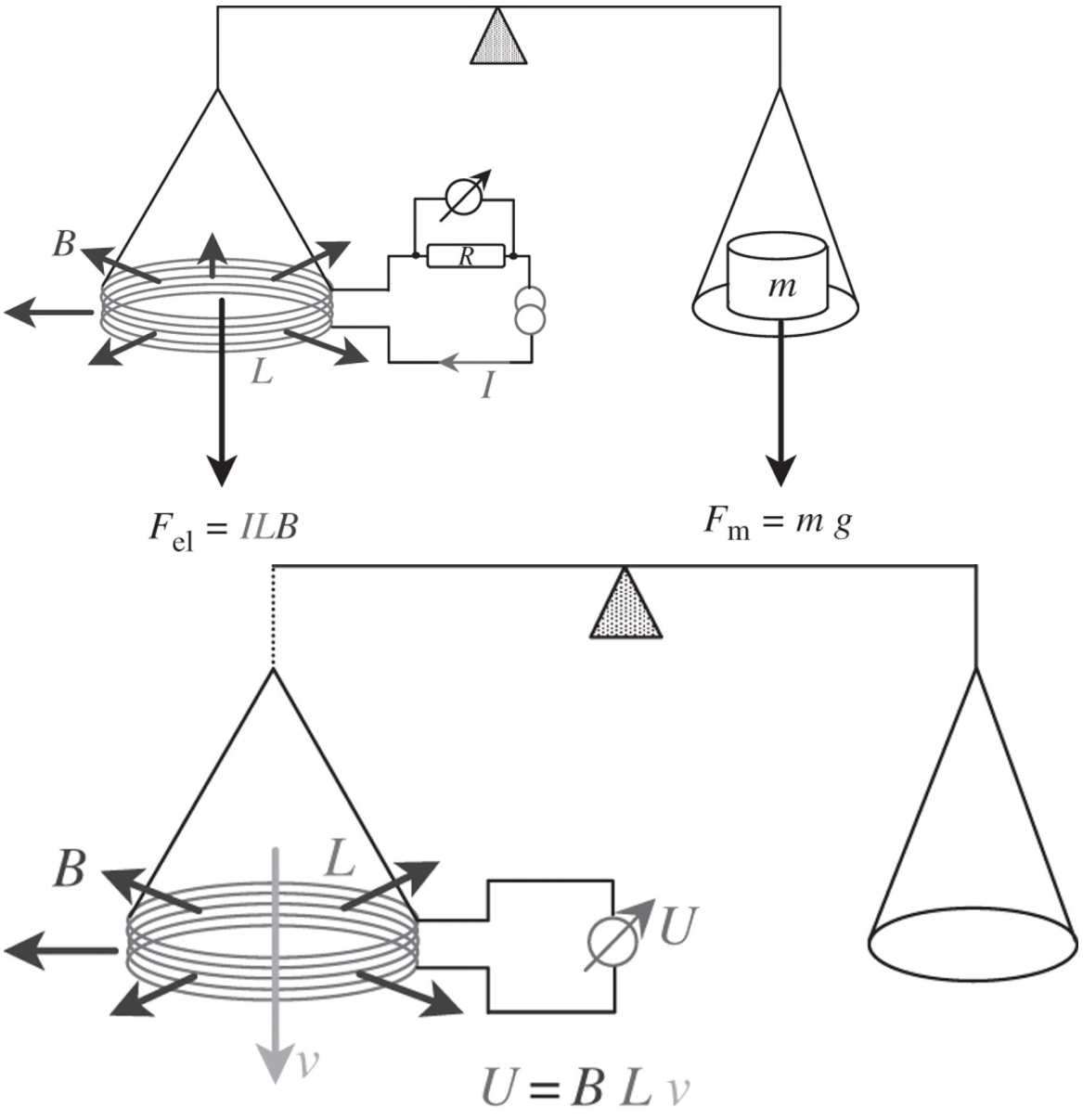
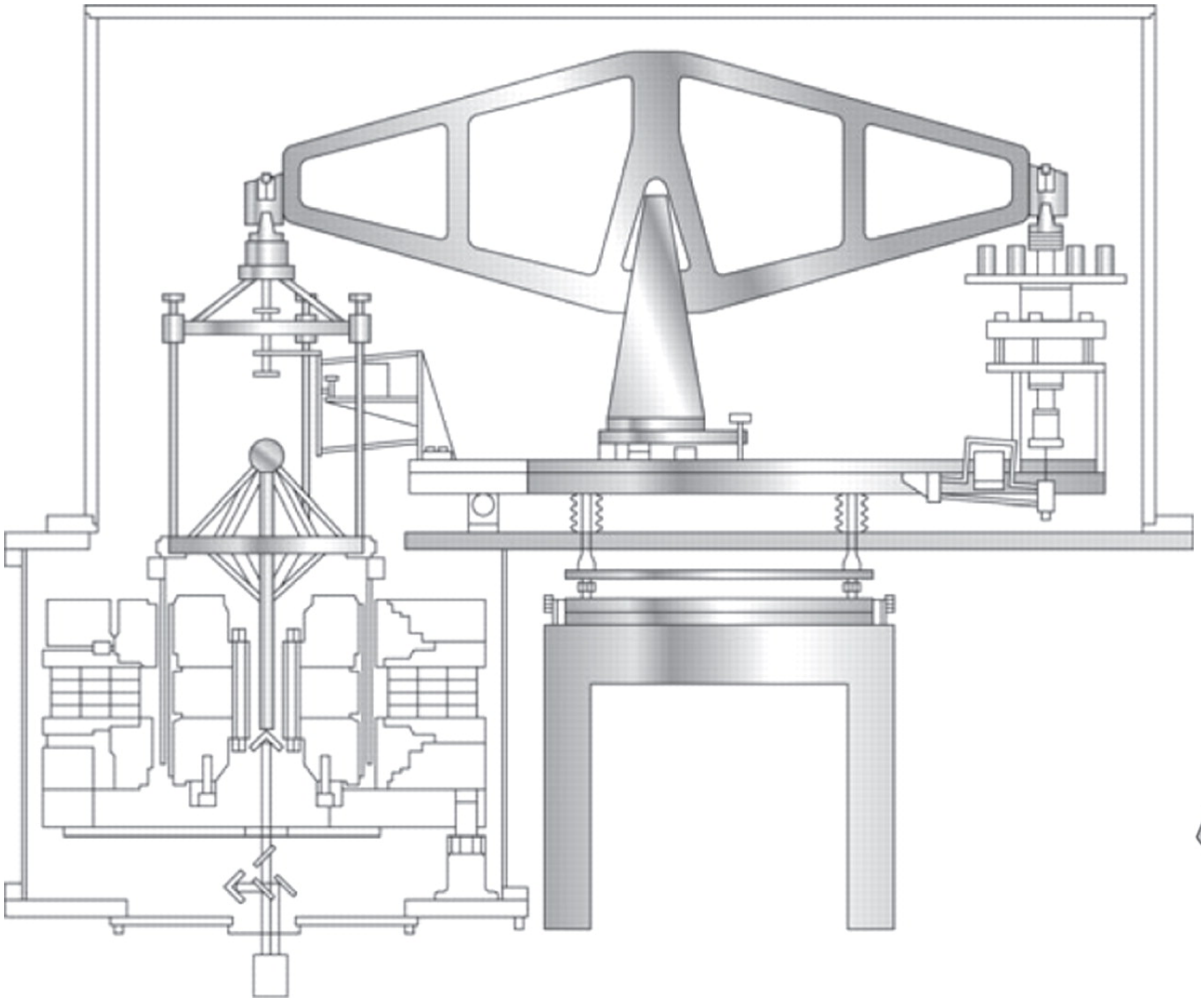
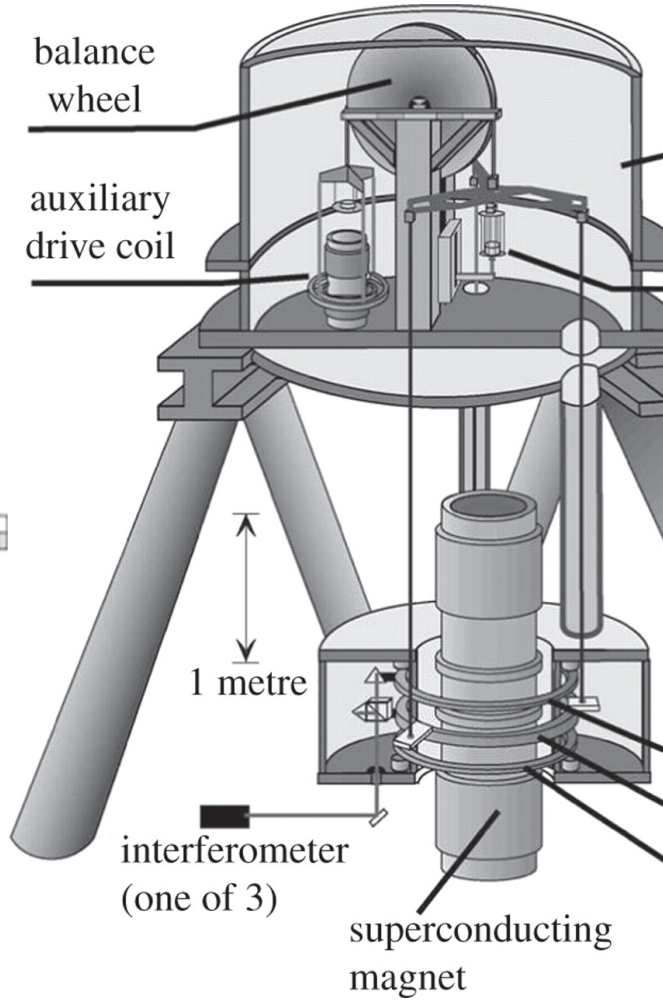
Watt balance: the principle



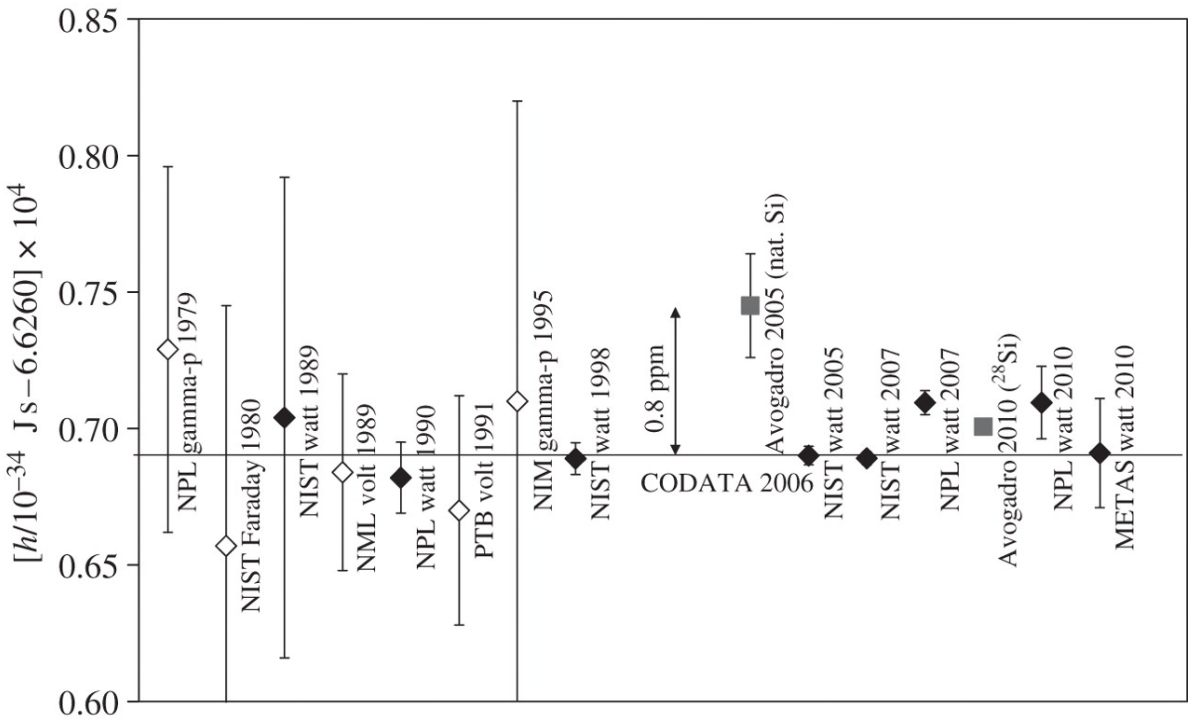
Josephson junction (1962, Nobel 1973)

Watt balance: the schematics





Progress in measurement of h



Conditions to be fulfilled

- At least three independent experiments, including work both from watt balance and from International Avogadro Coordination projects, yield values of the relevant constants with relative standard uncertainties not larger than 5 parts in 108
- At least one of these results should have a relative standard uncertainty not larger than 2 parts in 108.
- All experiments should be consistent at 95% level of confidence.
- xx

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