Redefinition of the Kilogram Through The Watt Balance

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INTRODUCTION

- The kilogram is currently the only SI base unit that is based off of a physical object
- This is a cause of uncertainty because the mass of a physical object can change over time
- The Watt Balance is a method of measuring mass that does not require a physical object for comparison or calibration
- The Watt Balance will be used to redefine the kilogram based on universal constants as of May 20, 2019.

OBJECTIVES

- Explain the reasoning behind the redefinition of the Kilogram
- Explain how the Watt Balance Works
- Show how the NIST design for the Lego Watt Balance can be created at home

Abstract

Since the establishment of SI units, there has been a continuous effort to improve the definition of these base units (meter, kilogram, second, ampere, Kelvin, mole, and candela) which comprise the basis of all calculations using more precise and fixed values such as Planck's constant, the elementary electric charge, Avogadro's constant, etc. The new definition for the kilogram will take effect on May 20th of this year. For reference, the standard for a kilogram is the International Prototype Kilogram and is defined by a platinum alloy cylinder stored in a protected vault in Paris. Since its creation in 1889, the mass of the cylinder has changed by nearly fifty micrograms. This standard for the metric system is the only mass on Earth defined with zero uncertainty. Through the effort to redefine the kilogram, the value will be derived via Planck's constant by using a watt balance. By using a watt balance – which utilizes electric current and voltage to measure a weight using a compensatory force - the kilogram can be redefined with a far more accurate and precise measurement. This balance, which has been built at the National Institute of Standards and Technology can be recreated on a smaller scale, within one percent uncertainty, to demonstrate the principles of the actual watt balance for educational purposes and demonstrations.

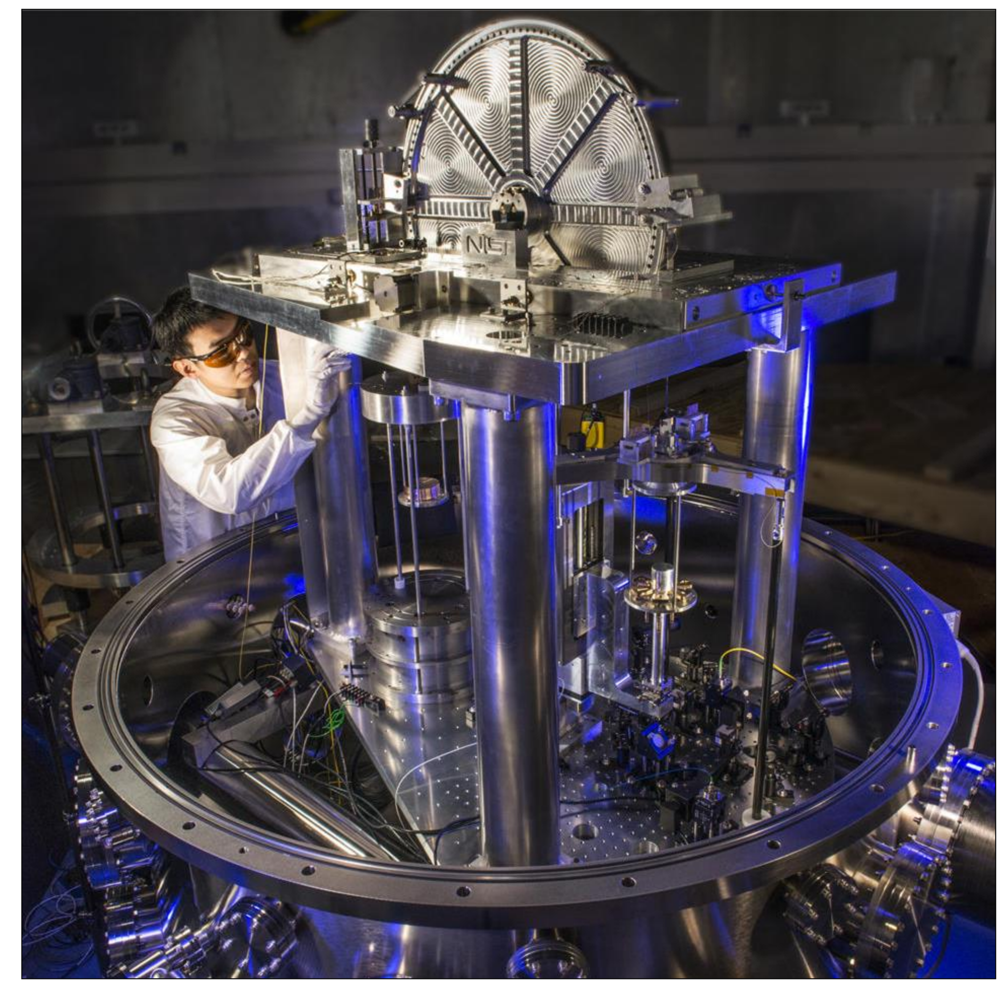

Figure 1. Watt Balance

Basic Watt Balance Theory

1) $V = BLv$

2) $F = BLI = mg$

3) $VI = mgv \rightarrow m = \frac{VI}{gv}$

4) $V = \frac{h}{2e} f \equiv K_J^{-1} f$

5) $R_H = \frac{V_h}{I} = \frac{1}{i}\frac{h}{e^2} \equiv \frac{1}{i} R_K$

6) $P = VV_R/R = Cf_1f_2 \frac{h}{2e}\frac{h}{2e}\frac{e^2}{h} = \frac{h}{e^2}$

7) $h = \frac{4}{Cf_1f_2} mgv \rightarrow m = \frac{Cf_1f_2}{4}\frac{h}{gv}$

8) $VI = mgv \rightarrow (VI)_{90}W_{90} = (mgv)_{SI}W_{SI}$

9) $\frac{(mgv)_{SI}}{(VI)_{90}} = \frac{W_{90}}{W_{SI}} = \frac{h}{h_{90}} \rightarrow h = h_{90}\frac{(mgv)_{SI}}{(VI)_{90}}$

10) $h_{90} \equiv \frac{4}{K^2_{J\text{-}90} R_{K\text{-}90}} = 6.626068...\text{x}10^{-34}$ J•s

11) $(BL)_v = \frac{V}{v}$ & $(BL)_F = \frac{mg}{I}$

12) $\frac{h}{h_{90}} = \frac{(BL)_F}{(BL)_V} = \frac{(mgv)_{SI}}{(VI)_{90}}$

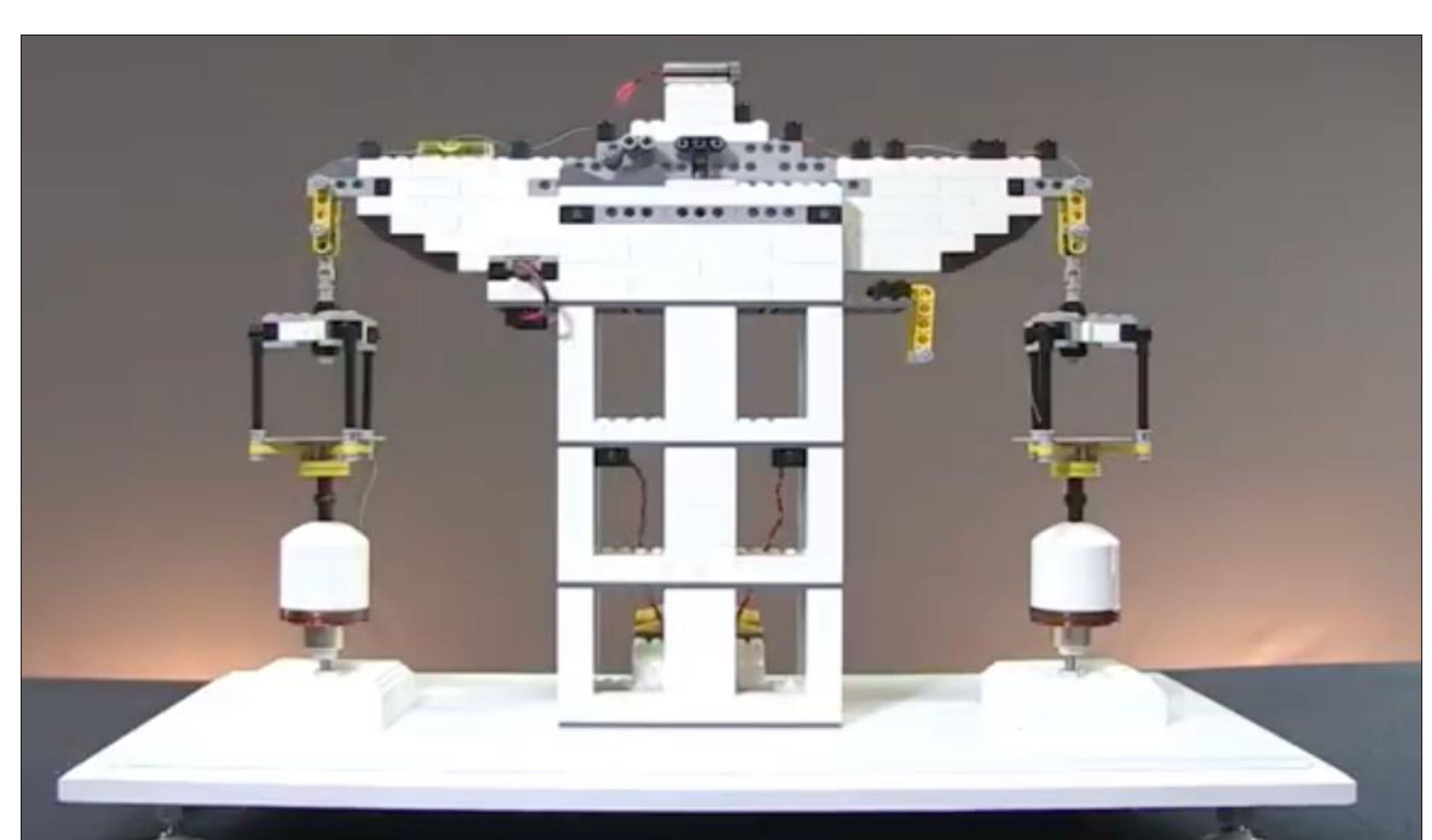

Figure 2. Lego Watt Balance

LEGO WATT BALANCE

- Lego parts and basic electronics needed
- Don't need to keep calibrating
- Changing amount of current flowing through coils moves balance up and down

COMPARISONS BETWEEN THE TWO BALANCES

	Watt	Lego
Balance Beam	Wheel	T-bricks
Weighing Scale	One Platform	Two on either side
Magnets	Bottom and Opposite from weight	Two Repulsive with Coils
Measurement	Laser and Fiber Optics on Table	Two Laser Pointers

FUTURE WORK

- Introduce physics and engineering students to uncertainty, electricity and magnetic fields
- Improvement to the design would be using cheaper alternatives for the DAQ (most expensive component and might be a limiting factor)

CONCLUSIONS

- Lego Watt Balance has uncertainty of 1%
- Program for the calculations and instructions to recreate the balance at home or in class provided
- Accurate Watt Balance built with ease at low cost
- Same principles as actual Watt Balance

References

Materese, Robin. "The NIST Do-It-Yourself Kibble Balance (Made with LEGO® Bricks!)." *NIST*, 17 May 2018, www.nist.gov/si-redefinition/nist-do-it-yourself-kibble-balance-made-lego-bricks.

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