Addition of a Magnet to Newton's Cradle

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(Dated: 22 June 2015)

Newton's Cradle is commonly used to demonstrate the conservation of momentum and energy; provided there is no outside influence on the system, an ideal Newton's Cradle can continue moving indefinitely. However, in reality, this is not the case. Energy is always lost to an outside force—friction—in an imperfect system, which is why there are no perpetual motion machines of the third kind in existence. In this paper, we investigate the opposite phenomenon; the effect of adding energy to a Newton's Cradle.

I. INTRODUCTION

Putting a magnet into a Newton's Cradle provides a way to add energy to the system. In this paper, we will compare the results of various different experiments: changing the number of balls in a standard Newton's Cradle, changing the beginning height in a standard Newton's Cradle, changing the number of balls in a Newton's Cradle with a magnet, and changing the beginning height in a Newton's Cradle with a magnet.

II. THEORY

Let us define the relevant equations in a standard Newton's Cradle:

$$F_{net} = m(a - \mu g) \tag{1}$$

$$p = mv \tag{2}$$

$$KE = \frac{1}{2}mv^2 \tag{3}$$

$$PE = mgh \tag{4}$$

$$m_1 v_1 = m_2 v_2 \tag{5}$$

$$KE_1 + PE_1 = KE_2 + PE_2 \tag{6}$$

These are all standard equations, taught in physics classes in schools. However, we are not just investigating a standard Newton's Cradle; we are also observing how adding energy through a magnet affects the system. In that case, let us define the additional equations we will need for the system:

$$F = \frac{\mu q_{m1} q_{m2}}{4\pi r^2} \tag{7}$$

Our approximate equation for the force in a Newton's Cradle with a magnet is then the following:

$$F_{net} = m(a - \mu g) + \frac{\mu q_{m1} q_{m2}}{4\pi r^2} \tag{8}$$

III. EXPERIMENTAL SETUP

We will investigate the following experiments:

1. How does the starting height of the ball bearing in the standard Newton's cradle affect the energy of the system?

2. How does changing the amount of standing ball bearings in the standard Newton's cradle affect the energy of the system?

3. How does changing the starting height of the magnet in the "magnetic" Newton's cradle affect the energy of the system?

4. How does changing the amount of standing ball bearings in the "magnetic" Newton's cradle affect the energy of the system?

For experiments (1) and (3), the setup is rather similar. In experiment (1), the ball bearing will be dropped from varying heights, and the energy of the rebounding ball bearing will be measured; experiment (3) will only see the dropped ball bearing replaced by a spherical neodymium magnet.

Experiments (2) and (4) also have similar setups. In experiment (2), the number of ball bearings between the dropped ball bearing and the rebounding ball bearing (at the end of the stack), will be changed. The ball bearings will be kept in place before collision by a pair of toothpicks. In experiment (4), the dropped ball bearing is again replaced by a spherical neodymium magnet.

IV. RESULTS AND DATA ANALYSIS

Table 1: Standard Cradle, Changing Height

Height	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average Energy
cm	J	J	J	J	J	J
0.50	0.00±0.05	0.00±0.01	0.00±0.01	0.00±0.01	0.00±0.01	0.00±0.01
1.00	0.01±0.05	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01
1.50	0.01±0.05	0.01±0.01	0.01±0.01	0.02±0.01	0.01±0.01	0.01±0.01
2.00	0.02±0.05	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01

Table 2: Standard Cradle, Changing Standing Bearings

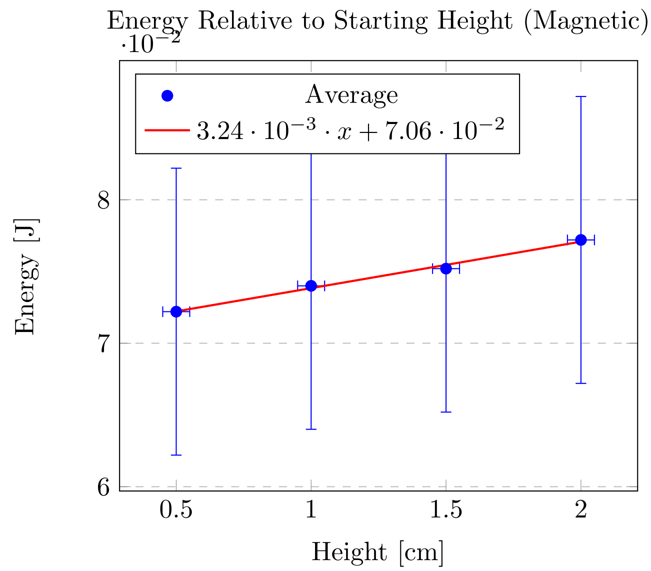
Count	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average Energy
	J	J	J	J	J	J
2	0.01±0.05	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01
3	0.01±0.05	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01
4	0.01±0.05	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01
5	0.01±0.05	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.01

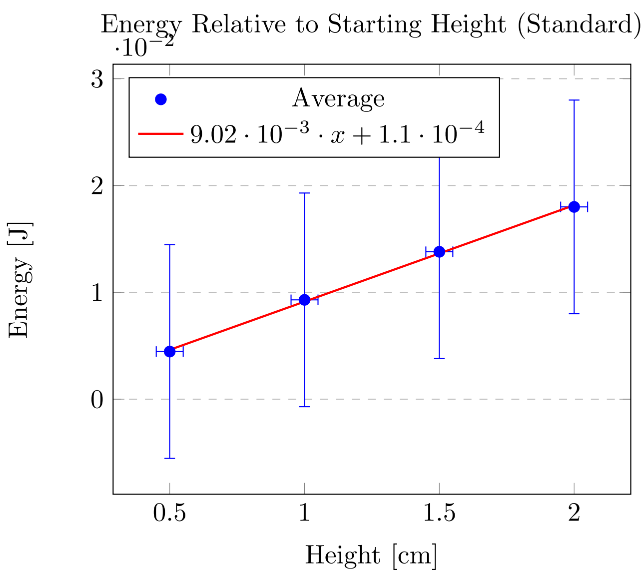
Table 3: Magnetic Cradle, Changing Height

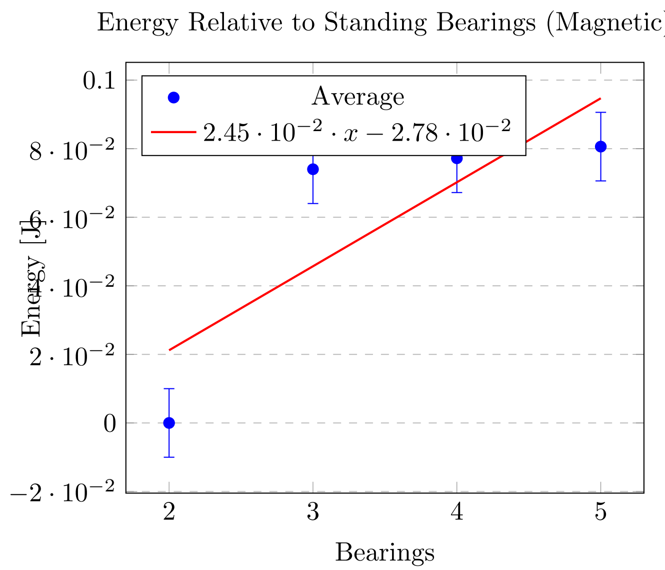
Height	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
cm	J	J	J	J	J	J
0.50	0.07±0.05	0.07±0.01	0.07±0.01	0.07±0.01	0.07±0.01	0.07±0.01
1.00	0.07±0.05	0.08±0.01	0.07±0.01	0.07±0.01	0.07±0.01	0.07±0.01
1.50	0.08±0.05	0.08±0.01	0.07±0.01	0.08±0.01	0.08±0.01	0.08±0.01
2.00	0.08±0.05	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01

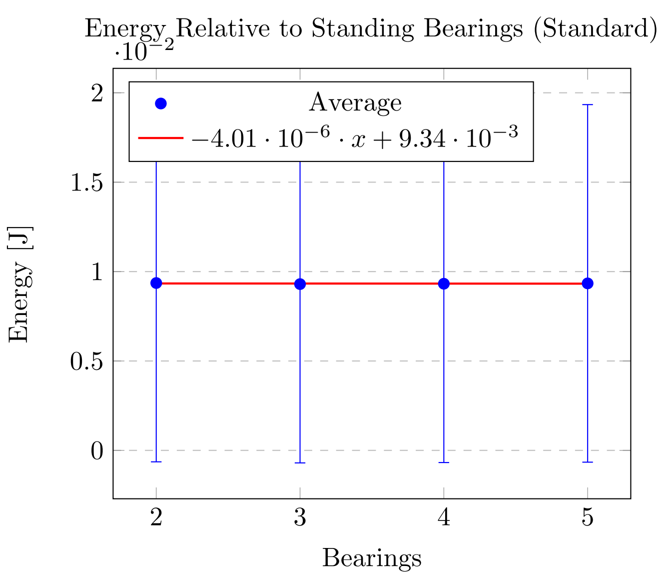
Table 4: Magnetic Cradle, Changing Standing Bearings

Count	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average Energy
	J	J	J	J	J	J
2	0 ±0.05	0 ±0.01	0 ±0.01	0 ±0.01	0 ±0.01	0 ±0.01
3	0.08±0.05	0.07±0.01	0.07±0.01	0.07±0.01	0.07±0.01	0.07±0.01
4	0.08±0.05	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01
5	0.08±0.05	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01









Above are all of the data that I collected. It immediately becomes clear that the Newton's Cradle with a magnet has more energy than the standard Newton's Cradle. A couple of interesting trends in the data can be seen. As the number of standing ball-bearings in the Newton's Cradle (with the magnet) increases, the ending energy of the rebounding ball also increases.

This can be explained using equation (7); as the number of standing ball bearings increases, the distance between the magnet and the rebounding ball bearing also increases. Magnetic force roughly follows the inverse-square law, meaning that as the distance between the objects increases, the force will decrease. Also important to note is the fact that the normal ball bearing is paramagnetic, meaning that its magnetic field will be proportional to the magnetic field strength at a given point. We can then observe that there are two terms in equation (7) with inverse correlation to the distance between the magnet and the ball bearing: r and q_{m2} (the magnetic field strength of the ball bearing). Knowing all this, we can see that the "pulling" force exerted on the rebounding ball bearing will be less as the number of ball bearings increases, as the distance between the ball bearing and the magnet will increase.

Another interesting trend is that while the energy of the rebounding ball bearing is higher with the magnet, the height only slightly correlates with the energy of the rebounding bearing. The correlation is much more pronounced in the standard Newton's Cradle, where the starting height is the only source of energy for the system, but with a magnet, there is another force acting on the system that compensates for the lack of starting height.

V. CONCLUSION

Though theoretically, the following is mathematically true:

- putting a magnet in a Newton's Cradle adds energy to the system
- the energy of the rebounding ball in the magnet-based Newton's Cradle is slightly dependent on the starting height
- the energy of the rebounding ball in the magnet-based Newton's Cradle is dependent on the number of standing ball-bearings between the magnet and the rebounding ball at collision

These conclusions are not supported by my experimental evidence. The error in my data is too large to allow for an accurate judgment of the above claims. In some cases, the error itself is over twice as large as the measured data ($0.5{*}10^{-2} \pm 1{*}10^{-2}$), which is very inaccurate, and, more importantly, physically impossible, as it would imply that the ball bearings could have negative energy, which is not possible.