Addition of a Magnet to Newton's Cradle

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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
cm	J	J	J	J	J	J
0.5	0.0044	0.0043	0.0045	0.0045	0.0046	0.004 46
1.0	0.0093	0.0094	0.0092	0.0092	0.0094	0.0093
1.5	0.014	0.013	0.014	0.015	0.013	0.0138
2.0	0.019	0.018	0.017	0.018	0.018	0.018

Table 2: Standard Cradle, Changing Standing Bearings

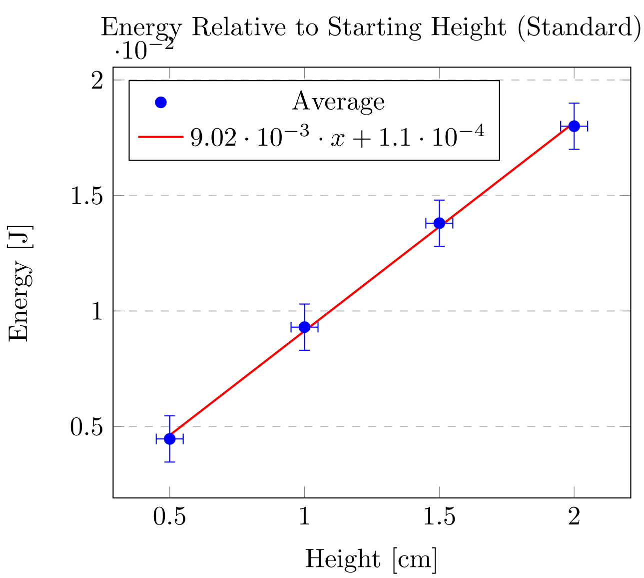
Height	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
cm	J	J	J	J	J	J
0	0.0094	0.0094	0.0095	0.0093	0.0092	0.009 36
1	0.0091	0.0095	0.0093	0.0093	0.0094	0.009 32
2	0.0092	0.0093	0.0093	0.0094	0.0093	0.0093
3	0.0094	0.0092	0.0095	0.0093	0.0093	0.009 34

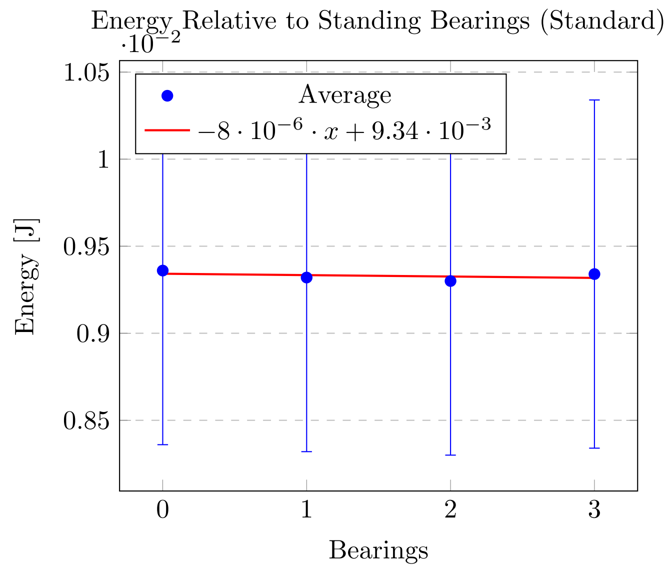
Table 3: Magnetic Cradle, Changing Height

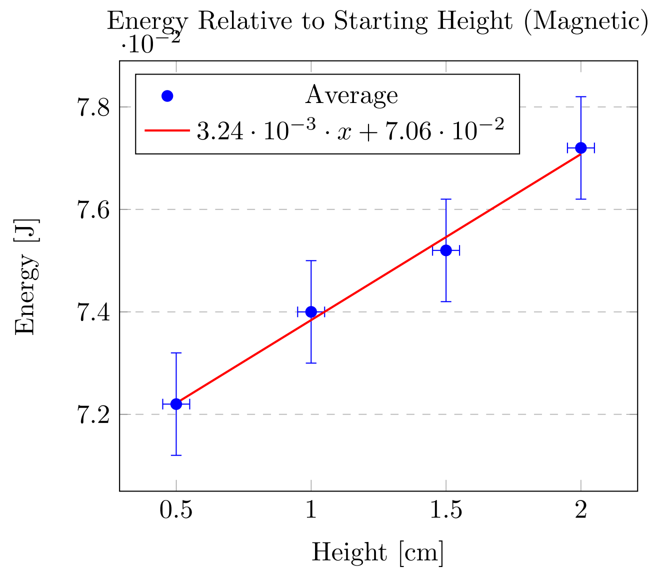
Height	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
cm	J	J	J	J	J	J
0.5	0.073	0.072	0.071	0.072	0.073	0.0722
1.0	0.074	0.075	0.074	0.074	0.073	0.074
1.5	0.076	0.075	0.074	0.076	0.075	0.0752
2.0	0.078	0.078	0.077	0.076	0.077	0.0772

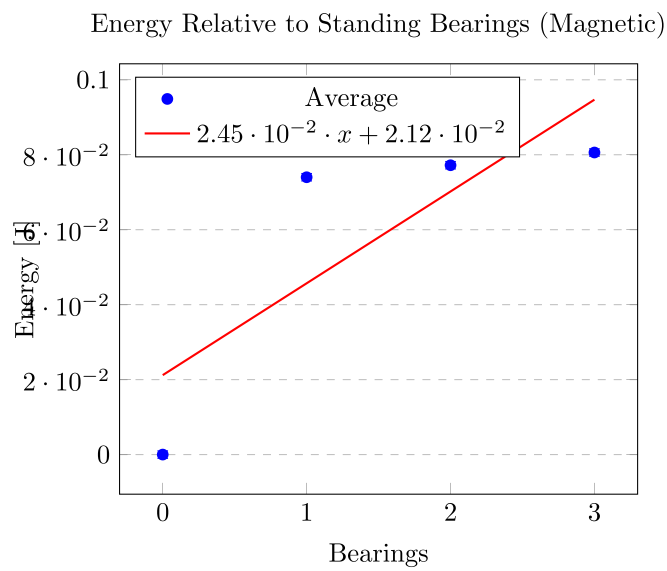
Table 4: Magnetic Cradle, Changing Standing Bearings

Height	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
cm	J	J	J	J	J	J
0	0	0	0	0	0	0
1	0.075	0.074	0.074	0.073	0.074	0.074
2	0.077	0.077	0.076	0.078	0.078	0.0772
3	0.080	0.081	0.081	0.080	0.081	0.0806









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

Through the four experiments, we can conclude the following:

- 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

While these conclusions are supported by experimental evidence, I found that in my calculations I did not have enough information to construct a meaningful model of the data, which is why I chose to adhere to a linear model for my graphs. So yes; there is a correlation between adding a magnet, starting height, and magnet separation to the final energy in a Newton's Cradle; however, further experimentation is required to determine the type of correlation (linear, square, logarithmic, etc.).