Measuring the Planck Length and the Speed of Gravity with a Newton Cradle and a Photogate

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Abstract

We demonstrate how one can remarkably use a simple Newton's Cradle combined with an accurate photogate (also known as time-gate or speed-gate) to deduce the speed of gravity, as well as the Planck length. We conducted 100 observations and found values quite close to those observed from other methods. The fact that we can extract the speed of gravity, as well as the Planck length, from just accurate measurements of the ball's speed in Newton's Cradle, is in line with the predictions from recent literature.

Index Terms

Newton cradle, Planck length, Planck time, quantum gravity, speed of gravity.

I. Finding the Planck Length and the Speed of Gravity Using a Newton Cradle and a Photogate

The velocity of the ball going out from an ideal Newton cradle is given by (see for example Ehrlich [1])

$$v_{out} = \sqrt{2gH(1-\cos\theta)} \tag{1}$$

This is naturally under ideal conditions. In practice, the balls will not be perfectly aligned, there is friction in the wires, some will convert into mechanical heat, and there is aerodynamic drag if not performed in a vacuum, etc. Nevertheless, even in practice, the formula derived under ideal considerations should be a good approximation, something we will revisit when discussing our experimental results.

In the special case $\theta = 90^\circ$, then $\cos\theta = 0$, and we can write the formula as:

$$v_{out} = \sqrt{2gH} = \sqrt{\frac{2GM}{r^2}H} \tag{2}$$

Max Planck [2], [3] in 1896 introduced the Planck units: a length $l_p = \sqrt{\frac{G\hbar}{c^3}}$, time $t_p = \sqrt{\frac{G\hbar}{c^5}}$, mass $m_p = \sqrt{\frac{\hbar c}{G}}$, and temperature $T_p = k_b = \sqrt{\frac{\hbar c^5}{G}}$. In 1984, Cahill [4], [5] suggested that the gravitational constant could be expressed by simply solving the Planck mass formula for G, which gives $G = \frac{\hbar c}{m_p^2}$. However, already in 1987, Cohen [6] pointed out that this seemed to simply lead to a circular problem as one had to know G in the first place to find the Planck units (using dimensional analysis), so then one could not simply use Planck units to find G. This view has been held until recently, see [7]. This, however, changed in 2017 where we, for the first time, demonstrated how to find the Planck [8] length using a Cavendish [9] apparatus independent of G, and later also without knowledge of both $\hbar$, G, and c, see [10], [11]. Based on this, we can indeed express the gravitational constant G from the Planck units, if we solve the Planck length formula with respect to G we get $G = \frac{l_p^2 c_g^3}{\hbar}$. This means the gravitational constant can be seen as a composite constant, many have suggested this, but first the recent methods discovered to extract the Planck length without knowing the gravity constant take us away from the circular problem, see [12] for an overview of the composite view of G. In addition, we must solve the Compton [13] wavelength formula $\lambda = \frac{h}{Mc}$ with respect to M which gives:

$$M = \frac{h}{\lambda}\frac{1}{c} = \frac{\hbar}{\bar{\lambda}}\frac{1}{c} \tag{3}$$

where h is the Planck constant and $\hbar = \frac{h}{2\pi}$ is the reduced Planck constant also known as the Dirac constant, further $\bar{\lambda} = \frac{\lambda}{2\pi}$ is the reduced Compton wavelength. This has been carefully discussed in multiple recent papers [10], [12], [14] that the Compton wavelength can be found for any mass without knowledge of G and also without knowledge of $\hbar$. Composite masses do not have a single physical Compton wavelength, but the single Compton wavelength used in the formula to find the kilogram mass of the mass is an aggregate of the individual Compton wavelengths from the masses making up the mass (one can even include such as binding energy in this approach), which are related by the formula:

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$$\bar{\lambda} = \frac{1}{\sum_i^n \frac{1}{\bar{\lambda}_i}} \tag{4}$$

Next, we replace G with $G = \frac{l_p^2 c_g^3}{\hbar}$ and M with $M = \frac{\hbar}{\bar{\lambda}} \frac{1}{c}$ and replace this into equation 2 above and solve for c_g, which gives:

$$c_g = v_{out} \frac{r}{l_p} \sqrt{\frac{\bar{\lambda}}{2H}} \tag{5}$$

where r is the radius of the Earth and $\bar{\lambda} = \frac{\hbar}{Mc}$ is the reduced Compton wavelength of the Earth, where M is the mass of the earth in kilogram, but this can also be found with no prior knowledge of the kilogram mass of the Earth or even without knowledge of $\hbar$, see [10].

Further the Planck length is given by:

$$l_p = v_{out} \frac{r}{c_g} \sqrt{\frac{\bar{\lambda}}{2H}} \tag{6}$$

One cannot determine both the speed of gravity and the Planck length from this approach. Calculating the speed of gravity requires knowledge of the Planck length, and conversely, determining the Planck length requires knowledge of the speed of gravity. However, we can first find the Planck length by utilizing the fact that it has been experimentally measured in recent years that gravitational waves move at a speed practically indistinguishable from the speed of light (see [15]). The idea that gravitational waves move at the speed of light has long been anticipated [16], but it has only recently been observed and confirmed. Therefore, when we aim to find the Planck length, we can simply replace c_g with the speed of light. And we can naturally measure the speed of light without needing any knowledge of G or any other information about gravity.

II. Experiment

We use a Newton's cradle and a photogate (BeeSpi V Self Contained Photogate) to accurately measure the outgoing speed of the ball in the Newton's cradle. The Newton's cradle setup with the photogate (speed-gate) is shown in Fig. 1. From the photogate, we can directly read the meters per second for the outgoing ball. For the photogate used, which is one of the most affordable and therefore well-suited for students and anyone interested in physics. We have to turn the photogate around to obtain readings, as illustrated in Figure 2.

Fig. 1: The figure illustrates Newton's cradle setup with a photogate (speed-gate). This is a straightforward and cost-effective experiment to perform. Unlike previously shown, we can use this setup to extract the Planck length and the speed of gravity.

We drop the ball from a height of about 11.5 cm ($H = 0.115$), which in our Newton's cradle corresponds to an angle of 90 degrees ($\theta = 90°$). We used a reduced Compton wavelength of the earth of $\bar{\lambda} = 5.68 \times 10^{68}$ m. Be aware that the reduced

Fig. 2: The figure shows the speed gate reading screen. One can directly read the speed in meters per second for the outgoing ball in the Newton's cradle. In this particular reading, the speed of the outgoing ball was 1.51 meters per second.

Compton wavelength of the Earth (or any other object) can be determined independently of knowing the mass of the Earth in kilograms or having any knowledge of $\hbar$ or G, as demonstrated by Haug [10].

We repeat this one hundred times and measure the outgoing speed of the ball to be between 1.4 to 1.58 meters per second. From each measured outgoing speed, we can derive the speed of gravity and the Planck length using equations 5 and 6, respectively. The results from the 100 ball drops and their measurements are shown in Table I.

We are not conducting this experiment to achieve more accurate measurements than other methods. Instead, our goal is to demonstrate that even from very simple gravitational experiments, one can surprisingly extract the speed of gravity and the Planck length. The average speed of gravity over these 100 measurements is $0.987c$, and the Planck length is also 0.987% of the CODATA 2019 Planck length (1.616255×10^{-35}). Our measurements, on average, are slightly lower than the likely real values. While the Planck length has a large uncertainty in its value, we know the exact value of the speed of light.

However, we expected our estimates to be slightly lower than the real values since we did not take into account air drag and the loss of heat energy when all the balls in the Newton's cradle collide. Our aim was not to obtain the most accurate observations; instead, it was to demonstrate that remarkably, a Newton's cradle can be used to extract the speed of gravity and the Planck length. This aligns with and has been predicted in a previous published paper by Haug [14], but this is the first time we have demonstrated this holds experimentally.

TABLE I: ONE HUNDRED MEASUREMENTS USING A SPEED GATE AND NEWTON'S CRADLE

Observation	v_o	c_g	c_g/c	l_p	**Observation**	v_o	c_g	c_g/c	l_p
1	1.40	278 977 798	0.931	1.51×10^{-35}	50	1.53	304 882 879	1.017	1.65×10^{-35}
2	1.45	288 941 291	0.964	1.56×10^{-35}	51	1.47	292 926 688	0.977	1.58×10^{-35}
3	1.54	306 875 578	1.024	1.66×10^{-35}	52	1.45	288 941 291	0.964	1.56×10^{-35}
4	1.49	296 912 085	0.990	1.60×10^{-35}	53	1.46	290 933 990	0.970	1.57×10^{-35}
5	1.54	306 875 578	1.024	1.66×10^{-35}	54	1.46	290 933 990	0.970	1.57×10^{-35}
6	1.51	300 897 482	1.004	1.62×10^{-35}	55	1.48	294 919 387	0.984	1.59×10^{-35}
7	1.48	294 919 387	0.984	1.59×10^{-35}	56	1.52	302 890 181	1.010	1.63×10^{-35}
8	1.53	304 882 879	1.017	1.65×10^{-35}	57	1.48	294 919 387	0.984	1.59×10^{-35}
9	1.46	290 933 990	0.970	1.57×10^{-35}	58	1.50	298 904 784	0.997	1.61×10^{-35}
10	1.51	300 897 482	1.004	1.62×10^{-35}	59	1.47	292 926 688	0.977	1.58×10^{-35}
11	1.51	300 897 482	1.004	1.62×10^{-35}	60	1.44	286 948 592	0.957	1.55×10^{-35}
12	1.45	288 941 291	0.964	1.56×10^{-35}	61	1.49	296 912 085	0.990	1.60×10^{-35}
13	1.44	286 948 592	0.957	1.55×10^{-35}	62	1.44	286 948 592	0.957	1.55×10^{-35}
14	1.49	296 912 085	0.990	1.60×10^{-35}	63	1.45	288 941 291	0.964	1.56×10^{-35}
15	1.53	304 882 879	1.017	1.65×10^{-35}	64	1.50	298 904 784	0.997	1.61×10^{-35}
16	1.47	292 926 688	0.977	1.58×10^{-35}	65	1.46	290 933 990	0.970	1.57×10^{-35}
17	1.51	300 897 482	1.004	1.62×10^{-35}	66	1.47	292 926 688	0.977	1.58×10^{-35}
18	1.46	290 933 990	0.970	1.57×10^{-35}	67	1.48	294 919 387	0.984	1.59×10^{-35}
19	1.50	298 904 784	0.997	1.61×10^{-35}	68	1.50	298 904 784	0.997	1.61×10^{-35}
20	1.48	294 919 387	0.984	1.59×10^{-35}	69	1.49	296 912 085	0.990	1.60×10^{-35}
21	1.49	296 912 085	0.990	1.60×10^{-35}	70	1.51	300 897 482	1.004	1.62×10^{-35}
22	1.48	294 919 387	0.984	1.59×10^{-35}	71	1.48	294 919 387	0.984	1.59×10^{-35}
23	1.52	302 890 181	1.010	1.63×10^{-35}	72	1.44	286 948 592	0.957	1.55×10^{-35}
24	1.52	302 890 181	1.010	1.63×10^{-35}	73	1.49	296 912 085	0.990	1.60×10^{-35}
25	1.48	294 919 387	0.984	1.59×10^{-35}	74	1.46	290 933 990	0.970	1.57×10^{-35}
26	1.51	300 897 482	1.004	1.62×10^{-35}	75	1.49	296 912 085	0.990	1.60×10^{-35}
27	1.55	308 868 277	1.030	1.67×10^{-35}	76	1.44	286 948 592	0.957	1.55×10^{-35}
28	1.54	306 875 578	1.024	1.66×10^{-35}	77	1.46	290 933 990	0.970	1.57×10^{-35}
29	1.55	308 868 277	1.030	1.67×10^{-35}	78	1.47	292 926 688	0.977	1.58×10^{-35}
30	1.47	292 926 688	0.977	1.58×10^{-35}	79	1.47	292 926 688	0.977	1.58×10^{-35}
31	1.49	296 912 085	0.990	1.60×10^{-35}	80	1.50	298 904 784	0.997	1.61×10^{-35}
32	1.51	300 897 482	1.004	1.62×10^{-35}	81	1.48	294 919 387	0.984	1.59×10^{-35}
33	1.56	310 860 975	1.037	1.68×10^{-35}	82	1.49	296 912 085	0.990	1.60×10^{-35}
34	1.48	294 919 387	0.984	1.59×10^{-35}	83	1.47	292 926 688	0.977	1.58×10^{-35}
35	1.47	292 926 688	0.977	1.58×10^{-35}	84	1.47	292 926 688	0.977	1.58×10^{-35}
36	1.46	290 933 990	0.970	1.57×10^{-35}	85	1.48	294 919 387	0.984	1.59×10^{-35}
37	1.49	296 912 085	0.990	1.60×10^{-35}	86	1.49	296 912 085	0.990	1.60×10^{-35}
38	1.46	290 933 990	0.970	1.57×10^{-35}	87	1.49	296 912 085	0.990	1.60×10^{-35}
39	1.52	302 890 181	1.010	1.63×10^{-35}	88	1.45	288 941 291	0.964	1.56×10^{-35}
40	1.53	304 882 879	1.017	1.65×10^{-35}	89	1.46	290 933 990	0.970	1.57×10^{-35}
41	1.54	306 875 578	1.024	1.66×10^{-35}	90	1.49	296 912 085	0.990	1.60×10^{-35}
42	1.53	304 882 879	1.017	1.65×10^{-35}	91	1.50	298 904 784	0.997	1.61×10^{-35}
43	1.45	288 941 291	0.964	1.56×10^{-35}	92	1.51	300 897 482	1.004	1.62×10^{-35}
44	1.44	286 948 592	0.957	1.55×10^{-35}	93	1.44	286 948 592	0.957	1.55×10^{-35}
45	1.48	294 919 387	0.984	1.59×10^{-35}	94	1.48	294 919 387	0.984	1.59×10^{-35}
46	1.44	286 948 592	0.957	1.55×10^{-35}	95	1.44	286 948 592	0.957	1.55×10^{-35}
47	1.45	288 941 291	0.964	1.56×10^{-35}	96	1.48	294 919 387	0.984	1.59×10^{-35}
48	1.50	298 904 784	0.997	1.61×10^{-35}	97	1.50	298 904 784	0.997	1.61×10^{-35}
49	1.58	314 846 372	1.050	1.70×10^{-35}	98	1.47	292 926 688	0.977	1.58×10^{-35}

The gravitational speed and Planck length are estimated from the velocity of the ball in Newton's cradle. The drop height is about 11.5 cm, and the drop angle is 90 degrees.

III. Conclusion

We have successfully demonstrated how one can extract the speed of gravity and the Planck length from a Newton's cradle. While this idea has been suggested before, this is the first time we have carefully demonstrated it through our experimental setup.

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