OBSERVE THE CHARACTERISTIC OF FEYNMAN RATCHET

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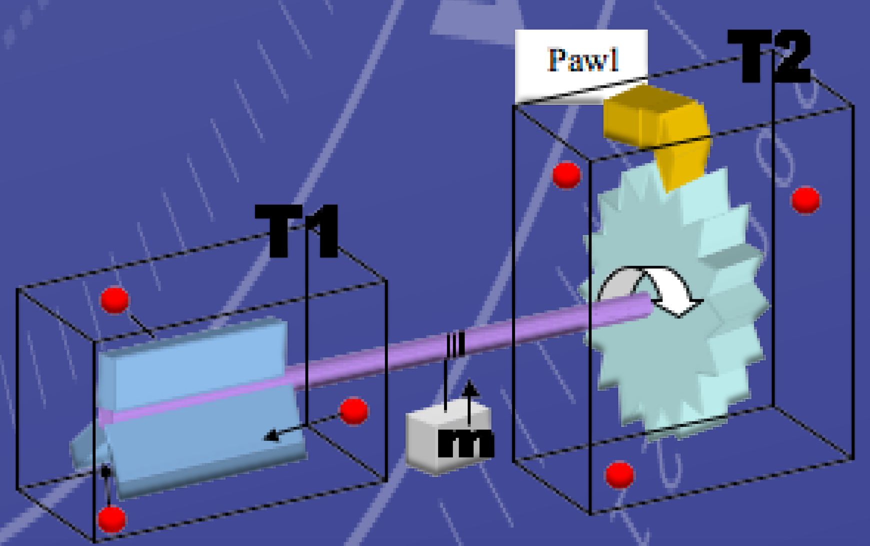
As a result of the gas molecules is difficult to observe. Our propose is using macroscopic setup to simulate microcosmic particles motion. We use airsoft pellets to replace the real gas molecules and enlarge the setup. Our goal is observe the phenomenon that the axis rotate at the random without ratchet and the axis rotate specific direction with ratchet. We get the two interesting results from the system without ratchet. The rotation degree likes mean squared displacement(MSD), and we can get the imaginary temperature is about 5.13×10^{18} (k) by Boltzmann distribution.

Introduction:

In the philosophy of thermal and statistical physics, Feynman ratchet is an imaginary experiment originally. Its setup consists of a ratchet that rotates freely in one direction but it is prevented from rotating in the opposite direction by a ratchet connecting with a pawl. There were many scientists believing that the device could produce work continuously. At the beginning, it seems to violate second law of thermodynamics. At last, the experiment confirmed the opinion was wrong. If the entire device is at the same temperature, the ratchet will not rotate continuously in one direction but will move randomly back and forth. There must be on both sides of the temperature difference will be observed the phenomenon. So it is the reason that the scientists couldn't get the result that they had expected.



(fig.1)

Setup:

Our experiment setup is divided into two part, the upper part (fig.2a) and lower part (fig.2b). (fig.2a) It includes a ratchet (a), two bearing (b), a blade (c), and a transparent film with a dot. (fig.2b) It includes a turntable (e), a polypeopylene block plate (f), a acrylic plate (g), motor (h), an aluminum fixture (i), and two box (j). The motor we use is four-wheel drive motor type No.15134, and it is driven with 5V, 2.4A. (fig.3) This is the appearance of our setup. The macroscopic particles are numbers of airsoft pellets (6mm diameter).

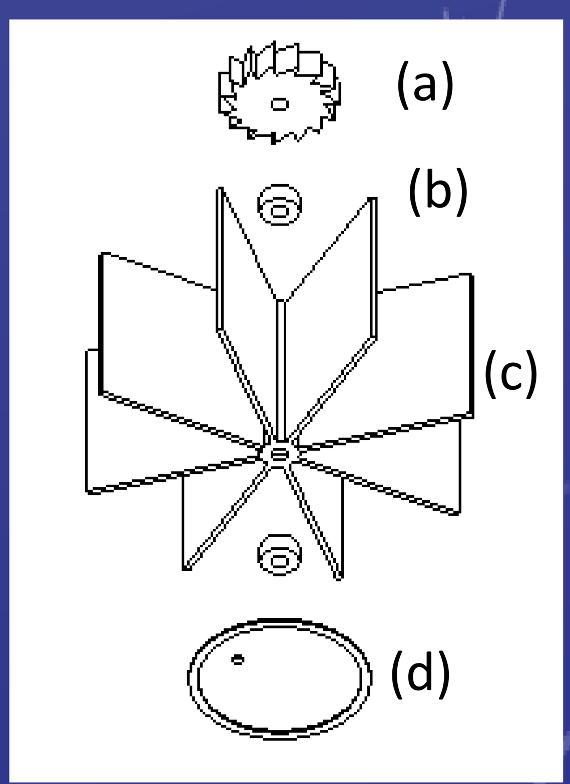


Fig.2a

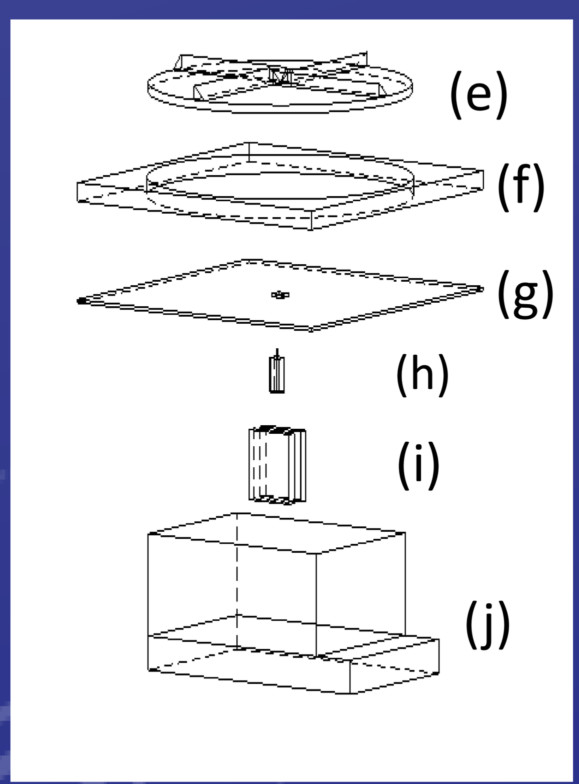


Fig.2b

Fig.2c

Method:

Our experiment is using a macroscopic particles, **airsoft pellets**, to simulate the microcosmic gas motion. We enlarge all setup comparing to real Feynman ratchet in order to observe the physics phenomenon easily. We made turntable rotate to hit the **airsoft pellets** to make their motion state like gas molecules perturbation. The **airsoft pellets** hit the blade like the gas molecules touch the blade.

To observe what angles and how fast the angular velocity is. We put a transparent circle slice with a black point on the axis. We use tracker to track the point and record the angle(θ) and angular velocity(ω) to analyze the distribution of the angular velocity and the energy.

We can simulate the temperature (Kelvin) by calculating the rotation kinetic energy(Eq. 1) of axis to get the Boltzmann distribution.

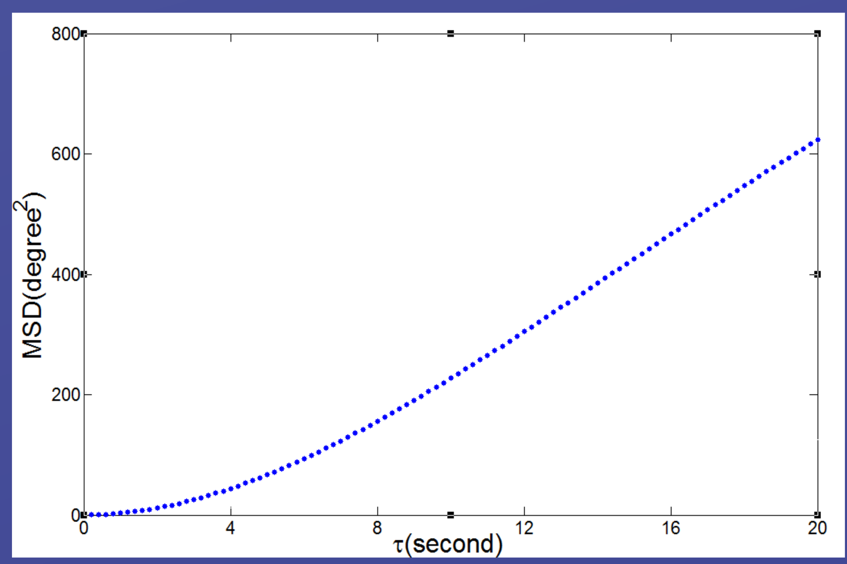
$$E = \frac{1}{2} I \omega^2 \qquad \text{(Eq.1)}$$

I : moment of inertia ω : angular velocity

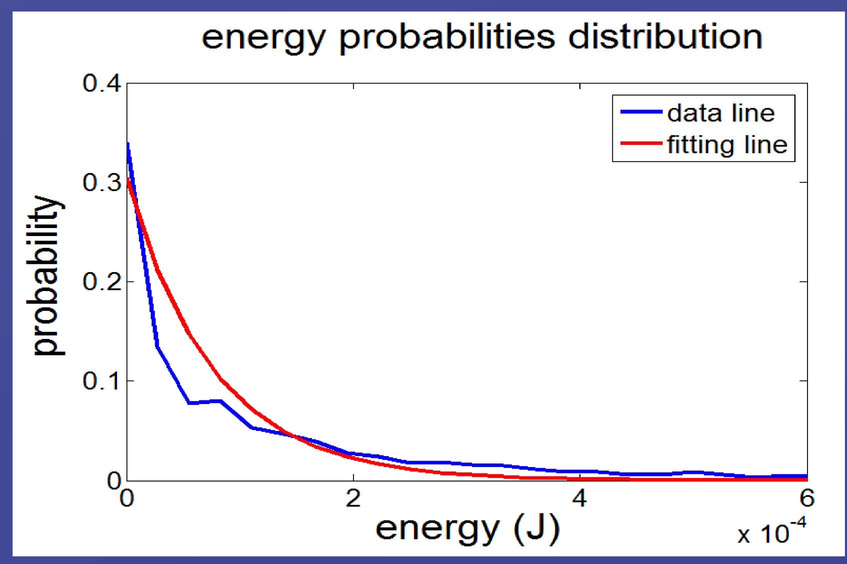
Result:

(1) Random motion in rotational degree of freedom.

As we thought before, the axis rotated at random without ratchet. In other words, the axis trended to rotated the specific direction roughly with ratchet. We observed that the rotation track of the no ratchet axis likes Brownian motion.



(fig.3)



(fig.4)

(fig.3) We analyze the mean squared displacement (MSD) of angle (no ratchet). The figure can be observed if we choose the time step from zero to four seconds, the motion will not be Brownian motion. As a result of not enough collision between particles and the blade.

$$MSD \equiv < (x(t) - x_0)^2 >$$

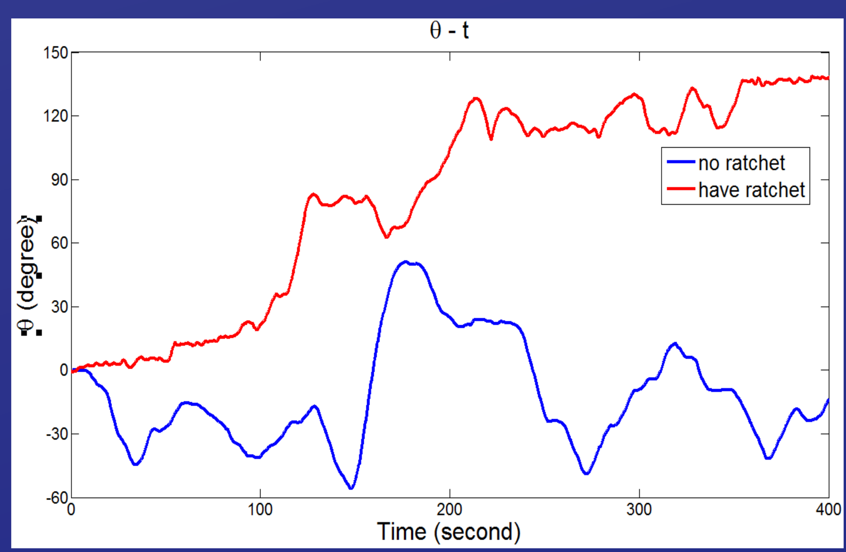
(fig.4) We fit the energy probability distribution with Boltzmann distribution. The result shows the temperature is about 5.13×10^{18} (k) by (Eq.2). This temperature is the value of the axis being thermalized.

$$p_i = \frac{e^{-\varepsilon_j/kT}}{\sum_{j=1}^{M} e^{-\varepsilon_i/kT}} \qquad \text{(Eq.2)}$$

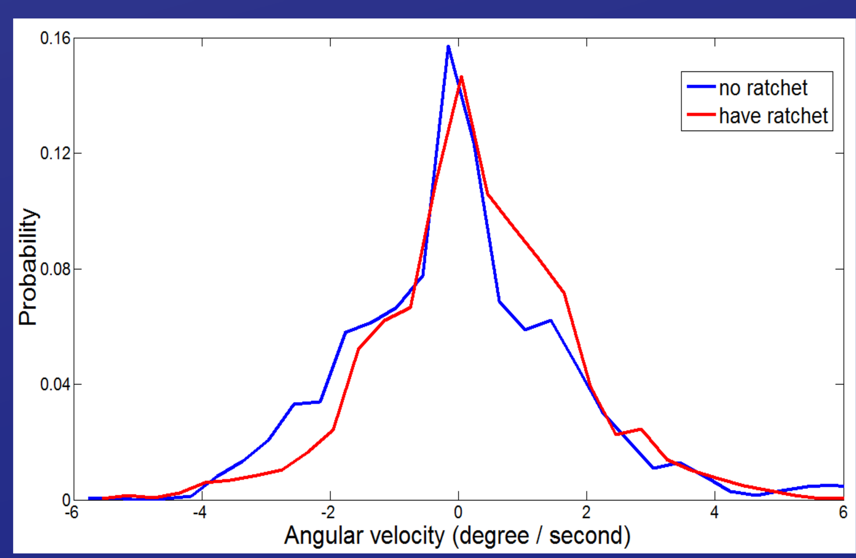
p_i : probability e : exponential constant T : Kelvin temperature

K : Boltzmann constant ε_i : the energy in condition i

(2)Feynman ratchet



(fig.5)



(fig.6)

(fig.5) The positive value means the counter clockwise rotation of the axis, while the negative value means the clockwise rotation.

(fig.6) From the distribution can be seen that the angular velocity difference between with ratchet or not.

Conclusion:

(1)The two different phenomenon of rotation between the two different systems about whether there is ratchet.

(2)The motion of axis without ratchet like Brownian motion at the time step from 4 to 20 second.

(3)We can infer out the imaginary system temperature by the Boltzmann distribution.

Reference:

(1) https://en.wikipedia.org/wiki/Brownian_ratchet
(2) P. Eshuis et al., Experimental Realization of a Rotational Ratchet in a Granular Gas, Phys. Rev. Lett. 104, 248001 (2010)