The Nature of Friction and the Analysis of Sliding Based on a Completely New Founding of Triboelectricity

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Abstract

Everything we know about science is temporary. Can we imagine that when the acrylic board was rubbed with silk, the generated electromagnetic field can drive the 14 W fluorescent tube lamps and the emerged electromagnetic attraction can draw the scissors and wood block swill around? When a wood box slides on a table, where the box slides, where the LEDs stocked right at the position of the sliding wood box under the table will be lit. Although numerous studies of sliding friction have been made and some empirical laws have been formulated, we have as yet, no clear understanding of the mechanism of friction. The effect of triboelectricity on the frictional force has not been studied and the nature of friction has not yet been finalized. In this paper, sliding friction was studied to investigate the nature of friction. We have found that the electromagnetic field will be generated when sliding happens, which leads to the generation of electromagnetic attraction. The generated electromagnetic attraction will accordingly affect the force of friction between two objects. Thus, we deduced that friction force should originate from the synergistic effects of the external resistance arising from uneven surfaces and the generated electromagnetic attraction. A slightly supplement and modification to the numerical formulas for calculating the sliding friction force is attempted to present. This study tries to unify the engagement theory and the adhesion theory and understand the nature of friction better. What's more, it will provide a novel perspective and open a new line of thinking for classical mechanics.

Keywords: Sliding Friction; electromagnetic field; electromagnetic attraction; friction force

1. Introduction

Friction is the force that opposes the relative motion or movement tendency of two bodies in contact with each other.[1, 2] The generated mechanism of friction has not yet been clear so far. From the fifteenth century to the eighteenth century, the engagement theory about the nature of friction was proposed. As the theory expressed,[3] the friction is generated by the rough surfaces of objects in contact. When two objects contact and squeeze with each other, lots of concave and convex portions on the contact surface mesh with each other. If an object slides along the contact surface, the bumps on two contact surfaces collide with each other, resulting in forming a barrier to movement. The rougher the contact surface, the greater the friction between two bodies. However, it cannot explain that the maximum friction between two objects will not reduce but increase when the contact surface is very smooth. In the middle of the last century, the new adhesion theory was addressed. No matter how smooth two contact surfaces are, at the atomic scale, they are rough and possess many tiny bumps [4]. If two surfaces are in contact, the tops of the micro protrusion come into contact. The squeezed surfaces will create atomic bonding and form attraction between atoms or molecules. Meanwhile, the surfaces of two objects seem to be "cold welded" together. If two objects slide relative to each other and along the contact surface, the adhesive force must be overcome, which exerts friction. In general, both of principles proposed by two theories can be used to explain the cause of friction. The principle of adhesion theory is more universal than that of the engagement theory. However, friction about different materials displays different mechanisms mentioned above. [5]The friction between metal is mainly generated by the adhesion, while the friction between wood is mainly caused by the mesh. The nature of friction is still inconclusive and under discussion.

According to the literature, friction can be divided into three types including static friction, sliding friction, and rolling friction.[6] When two surfaces are in sliding contact, the resistance occurring at the interface is defined as sliding friction. [3, 7] As extensively researches indicated, the amount of sliding friction depends on the magnitude of the pressing force between the contact surfaces and the roughness of the contact surfaces. It is generally believed that sliding friction increases with the increase of the pressure and the roughness of the surface. [8, 9]

Theories are constantly improved with the development of science. It is generally believed that the gravitational, electromagnetic, strong and weak interactions are the most basic interaction in nature.[10] Common collision and friction forces are caused by electromagnetic forces.[7, 11] Two objects can generate electromagnetic fields under the forces (tapping, friction, collision etc.).[12, 13] In this work, we have found the generated electromagnetic field can drive several fluorescent tube lamps, when we rub the acrylic plate with the silk. In addition, when a wood box slides on a table, the generated electromagnetic field can light the LEDs under the table corresponding to the position of the sliding wood box. And the resulted electromagnetic attraction can drive the scissors and wood block swill around. In other words, the friction between two objects will produce electromagnetic fields. Thus, the sliding friction was investigated to understand the nature of friction better. We have found that the effect of electromagnetic attraction is different depending on the materials, weight and roughness of objects in the friction. If all the electromagnetic energy generated by the friction is collected, we will find that the friction can generate a huge electromagnetic attraction. Friction should be attributed to the synergy of resistance force generated by the rough surface and electromagnetic attraction. Therefore, we have studied the calculation of sliding friction force from a new perspective and attempted to modify and improve the traditional calculation formula of friction. It is of great significance to deeply study the related fields of classical mechanics.

2. Results and discussions

How strong electromagnetic field and electromagnetic attraction can be produced by the sliding between two objects ? Figure 1a and Figure 1b respectively show the experimental setup and photo of the device for investigating the releasing of electromagnetic energy by the sliding. Rub the acrylic board with silk and see if there is the as generated electromagnetic field. As shown in Figure 1c-f, electromagnetic field will be generated when we rub the acrylic board with silk, and two 14 W fluorescent tube lamps were driven, which directly reflects how strong the as generated electromagnetic field can be. (Supplementary Video 1). In order to study the magnitude of electromagnetic field quantitatively, the electrical signals of the device were detected. Figure 1g and Figure 1h respectively show the as generated voltage can reach up to 4000 V and the as generated current can be up to 78 μA, when we rubbed the acrylic board with silk. In addition, the as generated electromagnetic field will lead to the generation of electromagnetic attraction. The resulted electromagnetic attraction can drive the hanged scissors and wood block swill around (Supplementary Video 2 and Video 3). From the angle of swing, we can roughly calculate that the as generated electromagnetic force is about one sixth of the weight of scissors and one fourteenth of wood block as shown in Figure 1i-n. The sliding between two objects will produce electromagnetic fields, which will generate the electromagnetic attraction accordingly. The direction in which the electromagnetic force occurs is vertically upwards or downwards the contact surface.[12, 13]

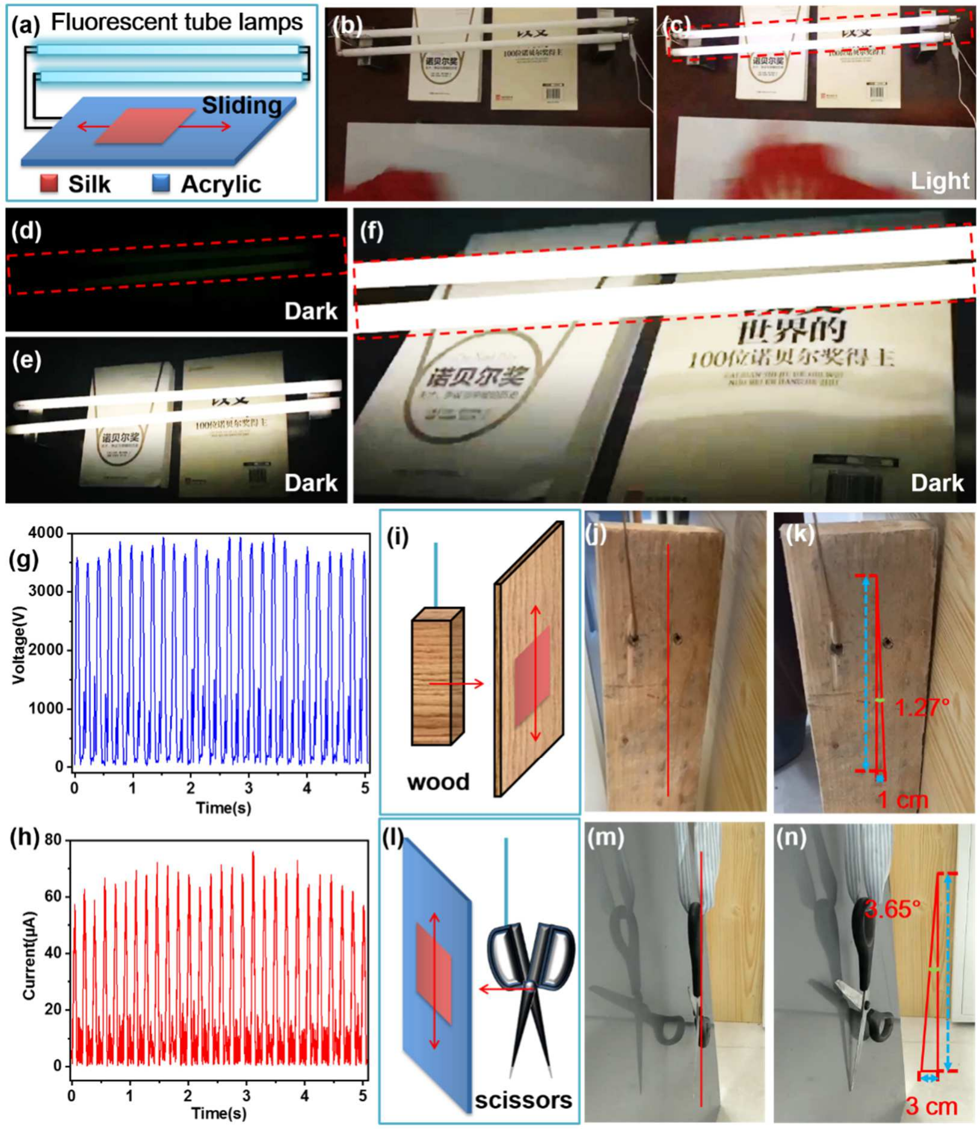

Figure 1. Electromagnetic field generated from the sliding. (a) Experimental setup of the device; (b) Photo of the experimental setup; (c) Two fluorescent tube lamps driven by rubbing the acrylic board; (d-f) Two fluorescent tube lamps driven by rubbing the acrylic board for reading the books; (g) The voltage of the device in the sliding friction; (h) The current of the device in the sliding friction; (i-k) The hanging wood bar is attracted to the wood board rubbed by the silk; (l-n) The hanging scissors is attracted to the acrylic board rubbed by the silk.

To investigate the influence of the electromagnetic attraction on sliding, we designed an experiment to show how strong the generated electromagnetic field by friction and how long it can persist. Figure 2a and Figure 2b show an experimental setup of power generation bar. The power generation bar was charged by rubbing with silk, and the electromagnetic field was generated by the friction. When the power generation bar was shaken above a large LED lamp board (1350 LEDs in series) from right to left, the large LED lamp board was driven wirelessly. (Figure 2c-2h) Because of the high speed of shaking, it is difficult to show the position of the power generation bar. It can be seen that the brightness of the LEDs is related to the position of the power generation bar, which is indicated by the dotted box. (Supplementary Video 4). Of course, the electromagnetic energy generated by the friction between the air and bar can also drive the LEDs too. However, it was not as strong as the electromagnetic field generated by friction between the silk and the bar. The power generation bar can still drive the LED board even after half an hour, which identified that the generated electromagnetic field can persist for a long time.

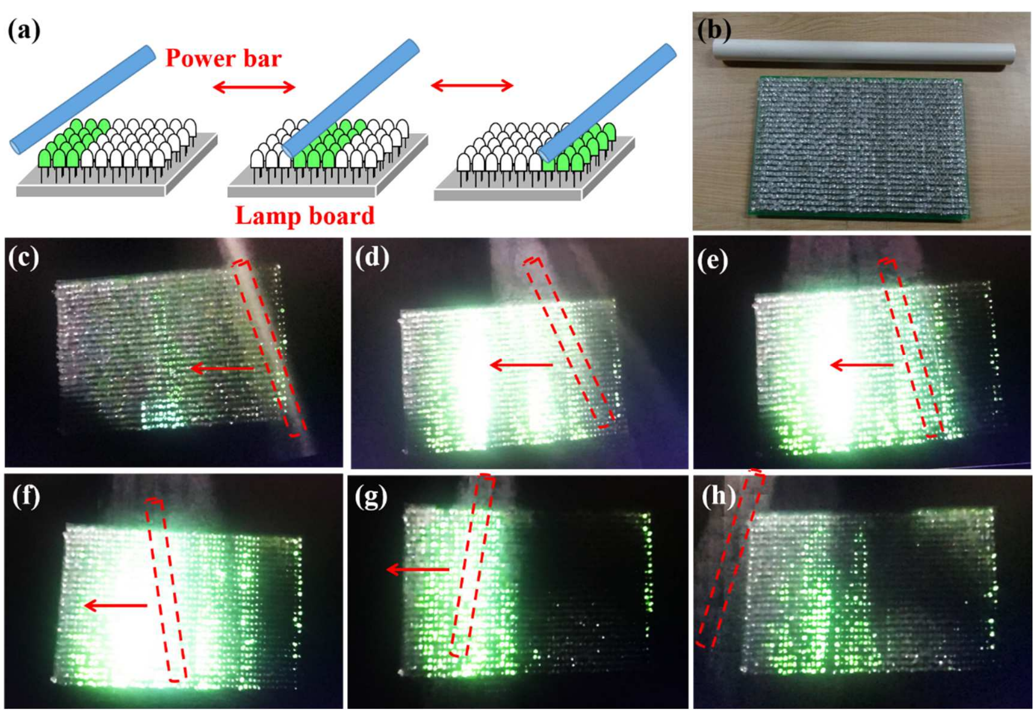

Figure 2. The power generation bar. (a, b) Schematic diagram and photo of the

experimental setup of power generation bar; (c-h) Photos of the large LED lamp board (1350 LEDs in series) driven by shaking the power generation bar above.

Sliding friction is the friction produced by the sliding of an object on the surface of another object, in which the direction of the friction force is opposite to the relative motion of the object. Will an electromagnetic field be generated when sliding friction happen? Figure 3a shows the experimental setup of the sliding friction device. We put the wood box on the wood board, then pulled it and let it slide on the wood board. The electromagnetic field is also generated when the box is sliding on the board. As shown in Figure 3b and Figure 3c, the maximum voltage of the device can reach up to 2100 V and the maximum current of the device can reach up to 35 μA, respectively. What's more amazing is that the electromagnetic field generated by the sliding friction can drive the LEDs, which is stick on the other side of the wood board. (Figure 3d and Figure 3e). The sliding friction occurred where the box was pulled. The sliding friction leads to the generation of the electromagnetic field. And the LEDs can be driven wirelessly, when the box passed over the LEDs. (Supplementary Video 5) Furthermore, the generated electromagnetic field will lead to the generation of electromagnetic attraction. As shown in Figure 3f and Figure 3g, the resulted electromagnetic attraction can drive the plastic particles under the wood board to run and jump with it. (Supplementary Video 6) In addition, we found that the quantity of electromagnetic field produced by sliding friction is related to the materials of the objects, weight of the object and the roughness of the contact surface.

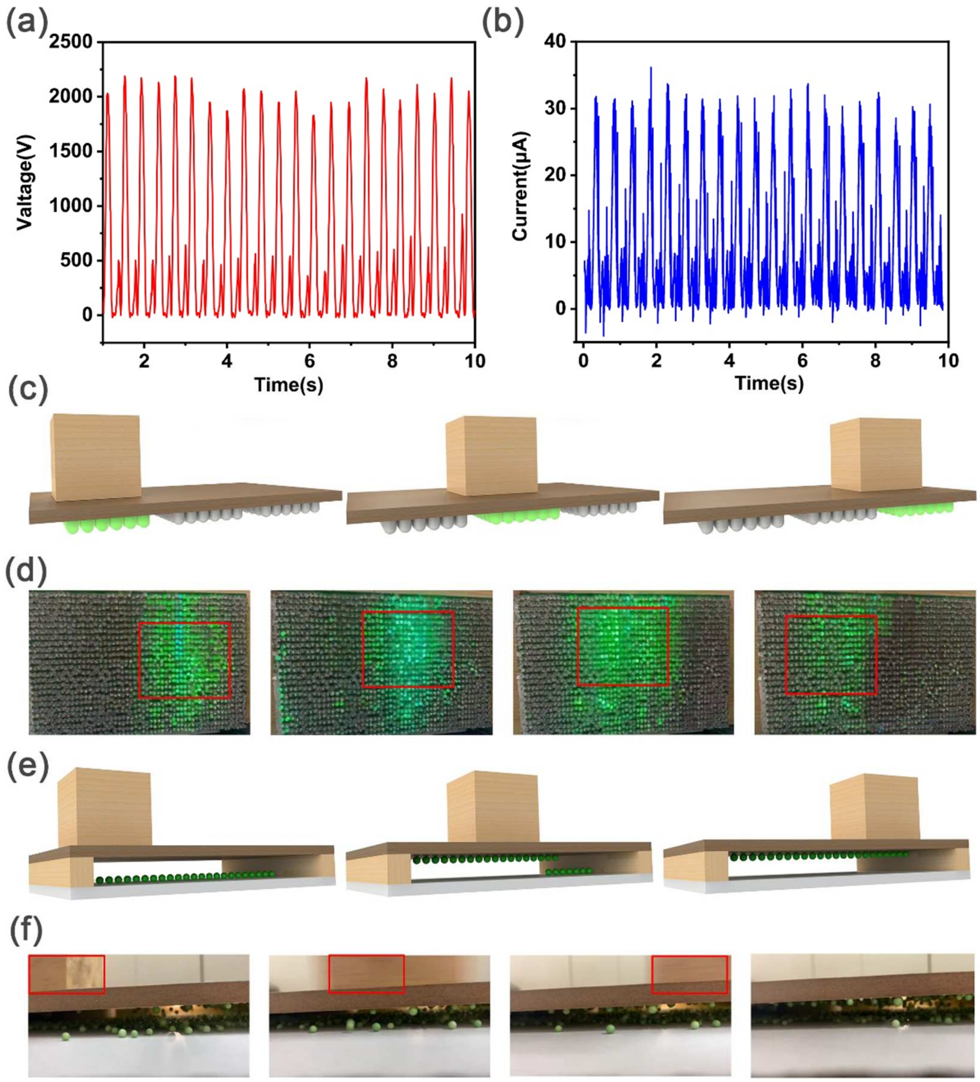

Figure 3. Electromagnetic field produced by sliding friction. (a) Schematic diagram of the sliding friction device; (b) The voltage of the device in the sliding friction; (c) The current of the device in the sliding friction. (d, e) Schematic diagram and photos of the LEDs were driven by the electromagnetic field generated by the sliding friction; (f, g) Schematic diagram and photos of the plastic particles were driven by the electromagnetic attraction.

We studied the influence of materials and weight of the objects on the strength of the electromagnetic field produced by sliding friction. Firstly, the boxes of different materials in the same design were pulled to slide (The sliding friction force is fixed) on the wood board to measure the as generated electromagnetic field. As shown in Figure 4a and Figure 4b, different materials can all produce the electromagnetic field, which will lead to the generation of electromagnetic attraction. Besides, both the voltage and current generated by the sliding friction between the wood board and the smooth wood box are higher than those of generated by the other boxes of different materials. Different materials of the objects have generated different electromagnetic field in the sliding friction, so the sliding friction is affected by the properties of the materials of the objects. Based on this, the wood boxes and metal boxes of different weight were chosen to investigate their influence on the strength of the electromagnetic field generated by sliding friction. Figure 4c and Figure 4d show the voltage and current generated by the sliding friction between the wood board and wood boxes with different weight (1.45 kg, 3.55 kg, and 6.35 kg). It can be found that the electrical outputs are decreased with the decreasing of weight of wood box in the sliding friction, and the heaviest wood box has generated the highest voltage and current. Figure 4e and Figure 4f show the voltage and current generated by the sliding friction between the wood board and metal boxes with different weight (2.85 kg, 5.00 kg, and 6.05 kg). Likewise, the heaviest metal box in the sliding friction has generated the highest voltage and current. Therefore, the voltage and current are increased with the increasing of box weight, which directly demonstrates that the electromagnetic fields increase as the weight of objects in the sliding friction. According to the above results, the strength of electromagnetic field as well as the electromagnetic attraction generated by the sliding friction is closely related to the materials and weight of the objects.

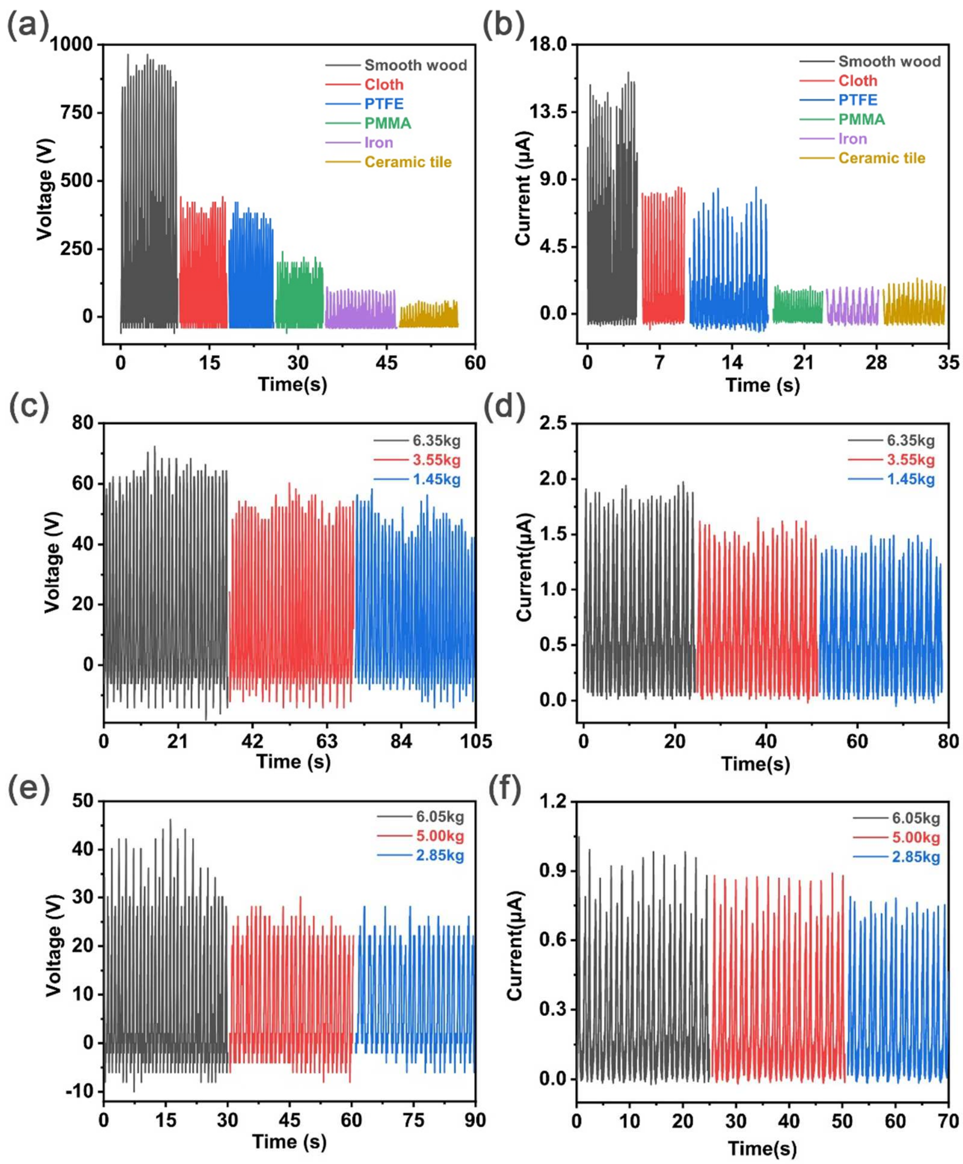

Figure 4. The influence of materials and the weight of the object on the strength of the electromagnetic field in the sliding friction. (a, b) Comparison of the voltage and current generated by the sliding friction between different materials; (c, d) The voltage and current generated by the sliding friction between the wood board and wood boxes with different weight; (e, f) The voltage and current generated by the sliding friction between the wood board and metal boxes with different weight.

The engagement theory states that the rougher the contact surface, the greater the friction force between two objects will be. However, it cannot explain why the sliding friction force generated between two metal surfaces increases when the contact surface becomes smoother. The adhesion theory believes that the generation of friction force is the result of molecule attraction. The smoother the contact surface, the better the adhesion between molecules, and the greater the friction force is. It is why the friction force generated between two metal surfaces increases when the contact surface becomes smoother. But it cannot explain why the friction force generated between two wood surfaces decreases when the contact surface becomes smoother. In order to improve engagement theory and adhesion theory and understand the nature of friction better, we investigated the roughness of contact surface on the strength of the electromagnetic field produced by sliding friction. Figure 5a and Figure 5b respectively show the experimental setup for studying the roughness of two wood surfaces and two metal surfaces. Different roughness of wood boxes and iron boxes of the same weight were prepared. Figure 5c and Figure 5d show the generated electromagnetic field when the wood boxes with different roughness slide on a same wood board. It can be found that both the output current and voltage are decreased with the increasing of roughness, which is contrary to the trend of sliding friction with roughness in the engagement theory. Figure 5e and Figure 5f show the generated electromagnetic field by the sliding friction between three iron boxes with different roughness and the iron board. We can see both the output current and voltage are decreased with the increasing of roughness. Surprisingly, the strength of the electromagnetic field generated between metal surfaces was consistent with the magnitude of the as generated sliding friction force according to the adhesion theory.

The as generated electromagnetic attraction increases with the intensity of the electromagnetic field. So the divergence between the two theories can be attributed to the generation of electromagnetic attraction. The effect of roughness on the sliding friction is weaker than the effect of electromagnetic attraction on the sliding friction, so the sliding friction force generated between metal surfaces increase when the contact surface becomes smoother. Compared with electromagnetic field generated by metal object, electromagnetic field generated by wood object is relatively weak, so the effect of roughness on friction is greater than the effect of electromagnetic attraction. This explains why the friction force that generated between two wood surfaces increases when the contact surface becomes rougher. In consequence, the friction force should originate by the synergy of the external resistance arising from uneven surfaces and the as generated electromagnetic attraction.

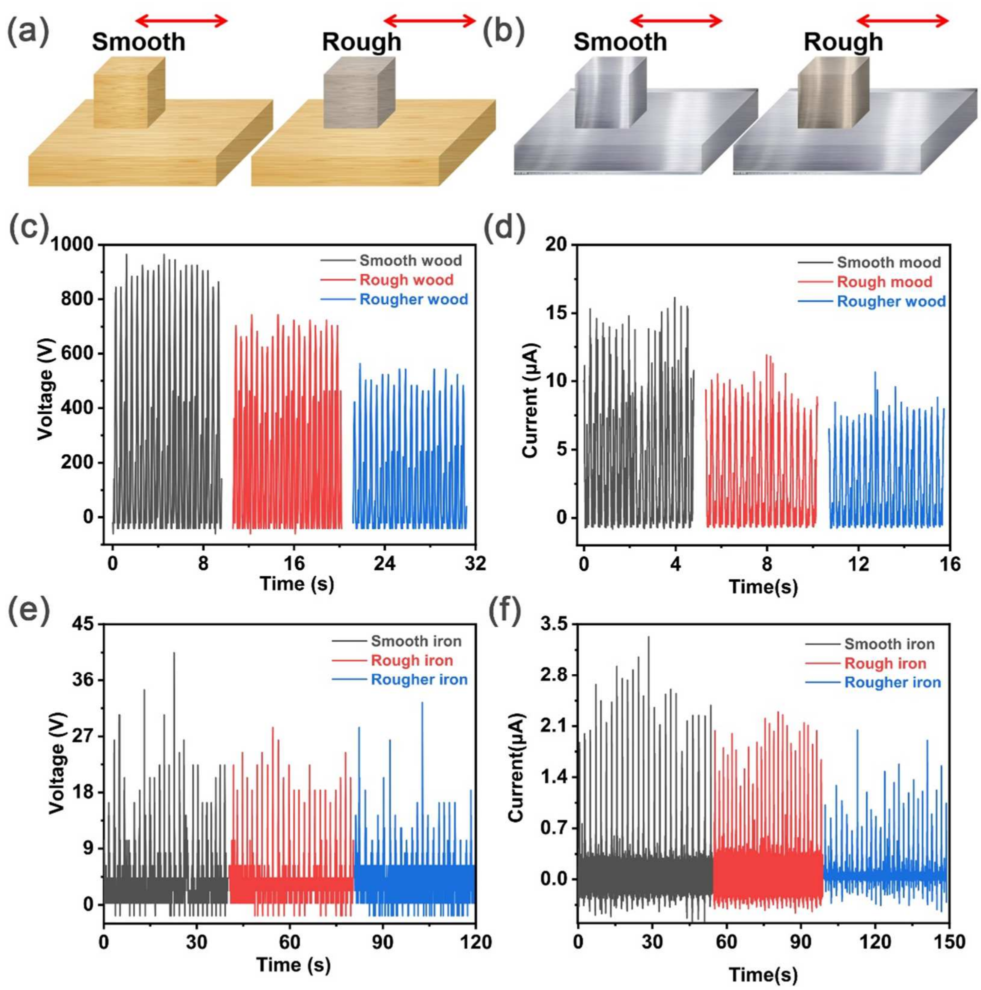

Figure 5. The influence of roughness of the contact surface. (a, b) Schematic diagram of the experimental setup for studying the roughness; (c, d) The voltage and current generated by the sliding friction of wood boxes with different roughness; (e, f) The voltage and current generated by the sliding friction of metal boxes with different

roughness.

The engagement theory believes that the smoother the surface, the smaller the frictional force that hinders relative movement. The adhesion theory believes that the energy loss caused by friction is not caused by the unevenness, but by the mutual interference of the gravitational field on the solid surface. The adhesion theory is explained from the perspective of microscopic molecules. We have found that electromagnetic fields will be generated by the friction. The generated electromagnetic field will lead to the generation of the electromagnetic attraction, which is destined to affect the magnitude of the friction. Based on the above research, friction force should originate by the synergy of the external resistance arising from the uneven surfaces and the generated electromagnetic attraction. Thus, we suggested combining the previous research with our latest findings to obtain the following calculation formula for sliding friction.

According to the traditional analysis of force, the formula is presented as (1). As shown in Figure 6a, when it is the sliding friction, the f is the sliding friction force, μ is the coefficient of sliding friction, N is the pressure, G is the gravity. Through our study, we believe that the composition of N should include electromagnetic gravity in addition to gravity. Thus, the force analysis of the object in the sliding friction can be performed as shown in Figure 6b. When the object is moving horizontally with uniform velocity on the contact surface, the object is subjected to forward tension, backward friction, normal upward force, downward gravity and electromagnetic attraction (F_{em}). Then the above formula should be calculated as (2). Classical friction theory believes that the friction force increases with the roughness (μ) of the contact surface. According to the formula (3-5), we can explain the divergence between the engagement theory and adhesion theory, which can be attributed to the generation of electromagnetic attraction. If it is assumed that μ_2 is greater than μ_1, F_{em2} is smaller than F_{em1} according to above research. L_1 is greater than 0, while L_2 may be greater than 0, less than 0 or equal to 0. Therefore, Δf may be greater than 0, less than 0 or equal to 0. We can see that the engagement theory is applicable to the judgment of the friction force when the L_1 is dominant. When the contact surface reaches a certain level of smoothness so that L_2 dominates, the engagement theory is no longer applicable. At this time, the effect of electromagnetic attraction is much greater than the obstructive force generated by the macroscopic unevenness, so the friction force is consistent to that of the adhesion theory.

$$f = \mu N = \mu \mathrm{G} \quad (1)$$

$$f = \mu N = \mu(\mathrm{G} + F_{\mathrm{em}}) \quad (2)$$

$$\Delta f = \mu_2(\mathrm{G} + F_{\mathrm{em2}}) - \mu_1(\mathrm{G} + F_{\mathrm{em1}}) = (\mu_2 - \mu_1)\mathrm{G} + (\mu_2 F_{\mathrm{em2}} - \mu_1 F_{\mathrm{em1}}) = \mathrm{L}_1 + \mathrm{L}_2 \quad (3)$$

$$\mathrm{L}_1 = (\mu_2 - \mu_1)\mathrm{G} \quad (4)$$

$$\mathrm{L}_2 = (\mu_2 F_{\mathrm{em2}} - \mu_1 F_{\mathrm{em1}}) \quad (5)$$

Besides, when the objects with the same mass and different roughness are in contact with the same plane, the generated friction force can be different. We have found the rougher contact surface in the sliding friction produced smaller current and voltage, when objects with different roughness slides against the same board. (Figure 5c-f) The electromagnetic attraction is positively correlated to the as generated electromagnetic field. Figure 6c and Figure 6d respectively show the sliding friction force between wood surfaces with different coefficient of sliding friction. As for the wood surfaces, the L_1 is dominant that the friction force increases with roughness. Figure 6e and Figure 6f respectively show the sliding friction force between metal surfaces with different coefficient of sliding friction. L_2 dominates in the sliding friction, the sliding friction force generated between metal surfaces increase when the contact surface becomes smoother. Importantly, our theoretical analysis is consistent with the experimental results in Figure 5c-f. As a result, the discovery of electromagnetic attraction and the improved calculation formula of friction have unified the engagement theory and the adhesive theory to a certain extent. It will provide a novel vision for the understanding of friction and classical mechanics.

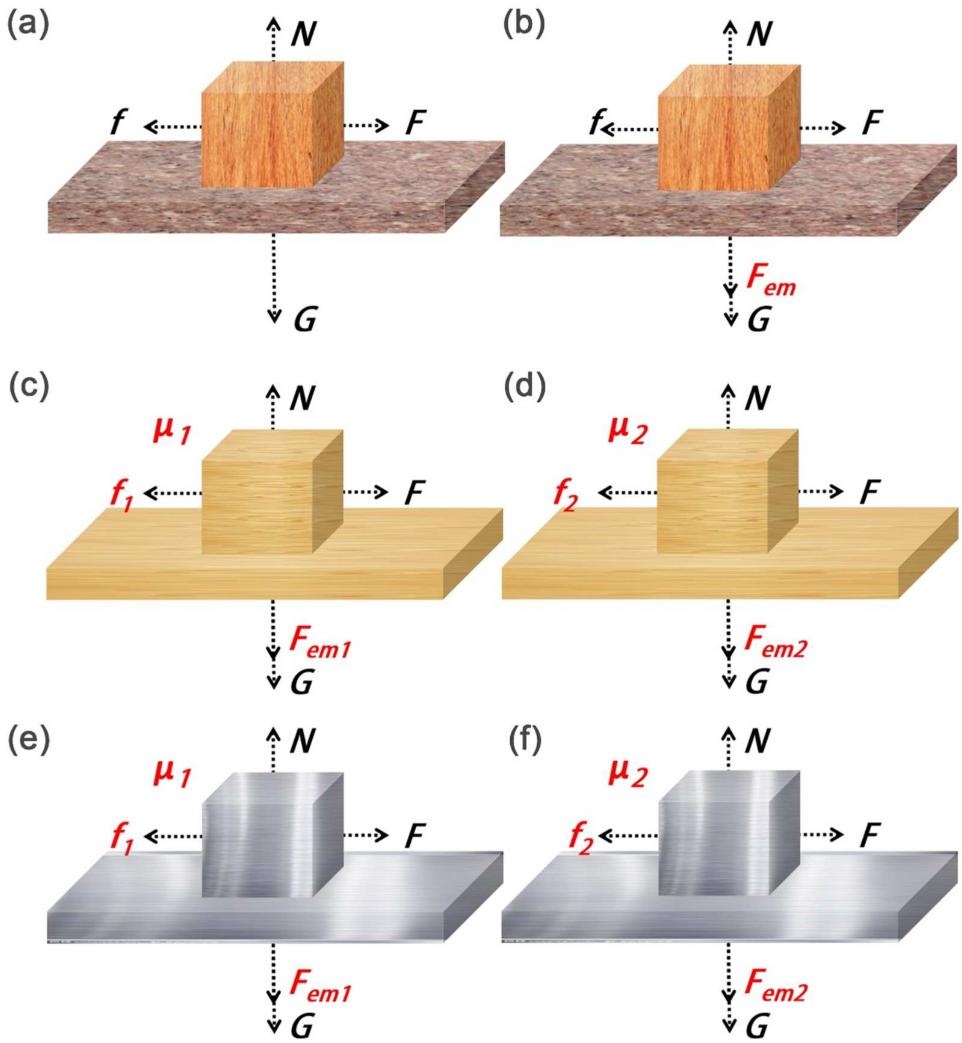

Figure 6. The analysis diagrams for sliding friction. (a) The traditional analysis of sliding friction force; (b) The new analysis of sliding friction force with the electromagnetic attraction; (c, d) The new analysis of sliding friction force between woods with different coefficient of sliding friction; (e, f) The new analysis of sliding friction force between metals with different coefficient of sliding friction.

3. Conclusions

In summary, we have found that electromagnetic field is generated when two objects under the friction force, which will lead to the generation of electromagnetic attraction between the contact surfaces. The as generated electromagnetic field can drive several fluorescent tube lamps, when we rub the acrylic plate with the silk. When a wood box slides on a table, the LEDs under the table can be driven wirelessly where the box passed over the LEDs. And the as generated electromagnetic attraction can drive the scissors and wood block swill around. By combining the engagement theory with adhesion theory of friction, we deduced that the sliding friction is originated by the synergistic effect of mechanical resistance and electromagnetic attraction. For the friction force, how big is the electromagnetic attraction? How much influence does the electromagnetic attraction have on the entire friction force? Through our testing, we have found that the effect of electromagnetic attraction is different depending on the materials, weight and roughness of objects in the friction. What we have measured so far is only a part of the electromagnetic field produced by the sliding friction, which is not all the as generated electromagnetic energy. If all the electromagnetic energy generated by the friction is collected, we will find that the friction can generate a huge electromagnetic attraction. Therefore, the generation of friction force probably is mainly derived from the electromagnetic attraction. A slightly supplement and modification to the numerical formulas for calculating the friction force in the sliding friction has been presented. Besides, we will further carry out more detailed research and more in-depth supporting analysis in the next work. This work provides a new example and a novel perspective for classical mechanics, especially for the friction. Moreover, it has important implication for deeply studying the related fields of classical mechanics.

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