# Actual justification of the Crooks and Nichols radiometers, and failure of solar sails

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**Abstract**

Radiation energy causes fluctuation of the molecules in vanes of the Crooks radiometer. Through this fluctuation, molecules of the vanes strike the adjacent air molecules and as reaction cause recoil of the vanes. It seems that this is also the mechanism of Nichols radiometer. But, in the vacuum of the space, there are not practically such molecules to be leaned by the striking molecules of the vanes of solar sails. So, the vanes will not recoiled to be propelled. It is shown that a comet's tail and antitail are common tides produced by Sun rather than by radiation pressure.

## 1 Introduction

Crooks radiometer is a bulb evacuated of air not completely. Inside is a set of vanes which are mounted on a spindle. Regularly, a side of each vane is black and the other side is reflective. When the set is exposed for visible or thermal electromagnetic radiations, the vanes turn in such a manner as if the force exerted on black surfaces is more than one exerted on reflective surfaces. This is not the radiation pressure, because this turn will cease when the vacuum becomes better (about $10^{-6}$ Torr or better). So, the pressure on the vanes is a secondary phenomenon arising from the existence of the molecules of the low pressure air in the bulb. To discover the mechanism of this phenomenon scientists have made several attempts without any notable success [1,2]. The last nearly accepted justification is (Osborne) Reynolds' force. It states that the warm air near the black surface ascends and then the cold air replaces it through a flow of air (or indeed a wind). This air flow or wind hits on the black surface on its course and pushes it [3,4]. In this paper we will see the weakness of this justification and will present the real cause of this phenomenon.

There is also Nichols radiometer in which the set of reflective vanes turns after radiating an electromagnetic wave directly on only one reflective surface in such a manner as if the radiation exerts pressure on the hit surface [5,6]. It is said that the cause of this phenomenon is electromagnetic pressure of the descending wave not the above-mentioned secondary phenomenon apparently because the warmth due to the radiation on the reflective surface has not been recognized to such an extent as causing the above-mentioned secondary phenomenon. But apparently if the surfaces are black, the radiation directed only on one surface will cause exertion of a pressure on the set which will be more than the mentioned pressure exerted on the reflective surface (contrary to the theory predicting that the elastic electromagnetic pressure exerted on a reflective surface must be (at most twice) more than the inelastic electromagnetic pressure exerted on the same surface when blackened). And apparently for its reason it is stated that here the heat created on the surface is enough to cause the above-mentioned secondary phenomenon and then to increase the pressure exerted on the black surface. In this paper we have presented some propositions to do some experiments which can determine whether or not the cause of turn in this radiometer is the same mentioned secondary phenomenon.

There are also some other empirical or experimental phenomena which are attributed to the existence of radiation pressure. One of them is the suspension of a water droplet (or any other proper tiny particle) on a laser beam radiated vertically beneath it. It is attributed to radiation pressure while, by presenting its real cause, we show here that it cannot be related to radiation pressure. Also, existence of tail for a comet is commonly attributed to radiation pressure of Sun's radiation. We explain in detail that the cause of creation of tail and antitail in a comet is the tide arising from Sun's gravitation rather than radiation pressure. When it is cleared that almost all the evidences presented commonly in support of the existence of radiation pressure are not sufficiently firm, we conclude that the cause of this fact that solar sails, in the good vacuum of space, are not propelled as expected due to radiation pressure of Sun's radiation is probably this fact that there is not at all such a pressure.

## 2 Current and proposed theories

Dip the lower half of a bucket into a liquid and suddenly take it out of it. Which part of the liquid around the empty space in (or on) the liquid, created after this sudden disappearance of the bucket, will fill this empty space first? It is clear that this space will be filled first from the bottom of this space because the pressure of the liquid is more at the bottom than at the lateral side. Similarly, when the warmed air adjacent to the black surface ascends, the empty space produced near the black surface will be filled from the bottom not from the side. In other words, the current of air near the (warmed) black surface is parallel to the surface (from bottom to the top) not perpendicular to it causing exertion of force on it. So, indeed, (Osborne) Reynolds' force does not exist to cause rotation of the vanes.

An electromagnetic wave transfers (a part of) its energy to two molecules of the black surface which are adjacent to each other. This causes the movement of these molecules just as if an explosive has exploded between them. So, one of them is forced toward the outside and the other one is forced toward the inside of the surface. But, these two molecules are bound to each other and to the whole surface through coherent springy forces. Thus, if the surrounding space is empty of anything, ie of any molecule, no net momentum is transferred to the surface. But, if there exist molecules of a rare air in this space, the molecule being forced toward this surrounding space will transfer some momentum to the air molecules being impacted by it, while the other molecule being forced toward the inside of the surface does not still (or at all (in the case of insulation)) have access to the molecules of the air at the other side of the vane and then almost all of its momentum will be transferred to the whole surface (or in fact the whole vane).

The situation is like a pressed spring: when its catch is released while it is suspended in a space free from gravity, no momentum will be transferred to the spring, and when its catch is released while an end of it is resting on a stiff ground, the spring will be bounced forcefully, and when its catch is released while an end of it is resting on an elastic surface (eg on a jelly), the spring will be bounced not as forcefully as on a stiff ground. The energy of the spring is counterpart of the energy of the electromagnetic wave transferred between the molecules, and the spring itself is counterpart of the molecules of the substance under radiation, and the stiff or elastic surface is counterpart of the air molecules adjacent to the substance under radiation.

About this example and its similarity to the main subject we must note the following points:

1: The surroundings of one side of the spring, where one end of it is situated, must be denser than the surroundings of the other side if the opening spring is to gain momentum.

2: The density of the side into which the spring gains momentum must be sufficiently small to let the acceleration of the spring due to its opening be sufficiently big and noticeable. (In other words we can suppose that the radiated electromagnetic waves cause (excess) movement of a definite number of the molecules of the surface similar to some opening springs, and because of their impacts on the leaned molecules of the adjacent gas there will be exerted force on the molecules of the surface. Now we can assume that both the above-mentioned definite number and leaned molecules of the adjacent gas will not noticeably alter when the pressure of the gas noticeably decreases. The chief alteration, if the gas pressure decreases, is that other molecules of the gas (which are more when the pressure is more) will exist no longer to hinder the body to get more acceleration. So, the body gets more acceleration.)

3: Mass of the spring must be sufficiently small to get sufficiently big acceleration when being opened.

An explanation about the first condition: Suppose the spring is asymmetric in such a manner that an end of it is joined to a mass more massive than one joined to the other end (which can exist not at all). If this spring is opened in an empty space, it won't gain momentum since it is not in contact with a material medium and no net force is exerted on it (although the energy of the spring is released). But, if the spring is situated in a material medium the density of which is the same for the two sides of the spring, then the spring will gain acceleration (or momentum) toward the side it is joined to the heavier mass when being opened, because it is clear that after the moment the spring is released, displacement of the heavier end of it is less than one of the other end of it, and since the distance of the leaned molecules from the end of the spring is the same for the two sides of the spring, the lighter end of the spring will lean on the surrounding gas molecules sooner than the heavier end of it, so, the spring is also driven toward the direction of the heavier end. This is the reason why in Crooks radiometer, although the densities of the medium at the two sides of each vane is the same, it gains acceleration toward the reflective side, because the vane is analogous with the above-mentioned asymmetric spring that the black side of it is the lighter end and the middle mass of it is the heavier end of the spring. Existence of the reflective side is necessary to have a nonzero net force exerted on the vane. Of course, if the situation is such that only one side can be warmed, the other side will probably not require to be reflective. Such a situation is probably created when a droplet of water is suspended in air due to a laser beam radiated under it [7], because the laser beam warms only the lower surface of the droplet. (Certainly, the cause of this suspension is not the so-called radiation pressure, because if it was the cause, there would be no reason for the droplet to remain suspended in a fixed altitude above and near the table and it would continue its ascent necessarily.)

Now, if for the above-mentioned asymmetric spring, the first condition is also true in this manner that the medium of the lighter (or black) side is denser, it will gain more acceleration.

## 3 Proposition for experiments

To eliminate the effects of the above-mentioned secondary phenomenon, perform the experiment of Nichols and Hull in a vacuum of order $10^{-6}$ Torr or better. If the reason of rotation of the mirrors in this experiment is really the radiation pressure, we expect this rotation to be more powerful in this vacuum than in air. If, instead, it is weaker, considering that the above-mentioned secondary phenomenon has been eliminated, we must conclude that the cause of rotation of the mirrors in this experiment is not the so-called radiation pressure but the same secondary phenomenon. But, if it is more powerful, we expect that if this experiment is performed in this vacuum for blackened vanes, due to inelastic collision with the black surfaces the force exerted on them, and so the power of rotation, to decrease. Knowing that which occurs really needs the performance of this experiment in such a vacuum.

Also perform Crooks experiment in vacuum of $10^{-6}$ Torr or a better vacuum with vanes totally reflective (without any black surface) and with radiating sufficiently strong laser beams normally on every other reflective surfaces. Compare the result of this experiment with this same experiment when being performed in a vacuum not as high as $10^{-6}$ Torr (ie when the air pressure in the lamp is more). Direction of rotation of the vanes is expected to be the same in these two experiments (as if the laser beams are exerting force on the vanes).

If the rotation in the first experiment is more powerful than in the second one, we should conclude the pressure named as electromagnetic radiation pressure is the cause of rotation and repeat the experiment with vanes having thorough black surfaces (without any reflective surface) to see whether, as expected for black surfaces, the power of rotation decreases or not. And if the rotation in the first experiment is weaker than in the second one, we must conclude that the cause of rotation, even for the reflective surfaces, is the above-mentioned secondary phenomenon not the so-called electromagnetic radiation pressure.

To verify practically what we presented theoretically about Crooks radiometer, I propose making the following radiometer, which I wish it is named as "Arman" radiometer, as follows: Alter the four-vane set of the Crooks radiometer in this manner that two opposite vanes of this set, eg $a$ and $b$ in Fig. 1, are positioned at a level higher than the level at which the two other vanes, $c$ and $d$, are positioned while the whole set is balanced on the middle spindle. Stick the thin glass blades $a'$, $b'$, $c'$, and $d'$ on the inner side of the glass body of the radiometer in such a manner that in a start position, which can be obtained by attraction of the vanes by a magnet outside the radiometer, the vanes are quite adjacent and close to the blades as shown in Fig. 1. Also in this state, the surface of each vane which is close to a blade must be black and by attraction of the magnet must remain in this state (ie close to the blades). (It is clear that the blades $a'$ and $b'$ are at a level higher than the level of $c'$ and $d'$ because the level of the vanes $a$ and

$b$ is higher than one of $c$ and $d$.)

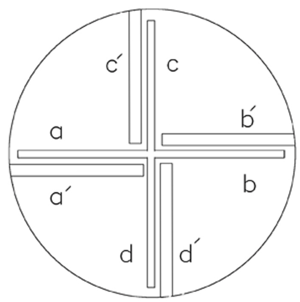


Fig. 1

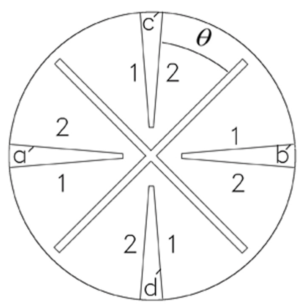


Fig. 2

Before beginning the experiment, while, through magnetic attraction, the vanes are still remained in contact with the blades, radiate (intense) thermal rays on the instrument. In this state in a moment take the magnet away from the instrument suddenly and measure the acceleration gained by the vanes through their 180° rotation by eg recording the time of this rotation. Compare this acceleration to the acceleration of the vanes in another radiometer which is quite similar except for the (fixed) blades which must not exist. If the first one is more than the second one, the theory presented in this paper will be confirmed experimentally.

Provided that this theory is confirmed by Arman radiometer, we can probably make a new kind of actinometer, which I like to name it as "Arman" actinometer, through the following method: Make an Arman radiometer with these differences: 1. The fixed thin blades of it are in fact wedges each side of which is along a radius of the container (as shown in Fig. 2). The kind of each blade is a nonconductor (eg a glass), and both sides of each blade is blackened. 2. The vanes are thin. The kind of vanes is a transparent glass and none of the sides of each vane is blackened. In this state the angle between the sets of vanes and blades (from 0° to 45°) is expected to be proportional to the intensity of the radiation fallen on the fixed black surfaces of the blades. For example if the radiation is fallen chiefly on the surfaces 1 of the blades, $\theta$ is expected to be about 0° practically, and if on the surfaces 2, it is expected to be about 90°. It is clear that if the intensity of radiation on surfaces 1 and 2 are equal, $\theta = 45°$ is expected, and if eg the intensity of radiation on 2 is more than one on 1, $\theta > 45°$ is expected. So, this instrument can be used for approximate measurement of the intensity of radiation.

# 4 Solar sail

Since, based on apparent theoretical and empirical evidences, it has been already thought that certainly radiation pressure exists, scientists were encouraged to use radiation pressure of sunshine to propel some kind of spacecraft named as solar sail. But, contrary to several experiments performed in this respect in space, and while they can suitably be deployed in space, there is not yet any decisive report that the sunshine radiated on them has acted as a propulsion force, at least to the extent expected theoretically. For example, although on February 4, 1993, the Znamya 2, a 20-meter wide aluminized-mylar reflector was successfully deployed from the Russian Mir station, propulsion was not demonstrated. In fact, many other similar experiments were also successful in deployment but failed in propulsion [8,9]. And even for IKAROS [10] there is no decisive report about propulsion and it has been stated that the data showed that it appeared to have been solar-sailing.

According to what presented in previous sections about radiation pressure, it is unlikely that the desired result will be gained in these experiments, because firstly, due to the construing from the experiments of Nichols, Hull, and Lebedev [11], it is thought that for detecting the radiation pressur in vacuum, the surfaces are better to be reflective than being black, and secondly, it is not probable there exist sufficient molecules in interplanetary space to be leaned by the striking warmed molecules of the vanes in order to push the sail.

# 5 Comet's tails are tides due to Sun's gravitation

It is said that a comet tail is due to radiation pressure of Sun's radiation. We now show this is not the case and it is because of the tide of comet coma arising from Sun's gravitation. Before that, it is necessary to study the reason of tide on Earth.

Suppose that the whole surface of the solid part of Earth is filled with a fluid. There is a greater sunward force on that part of this fluid that is closer to Sun than to the mass center of Earth which is farther. So, the fluid existent on this part is drawn toward Sun and a bulge is formed on the fluid in this part of Earth. This is the same sunward tide related to the Earth's part closer to Sun. But simultaneously, there is also a bulge on the fluid at the opposite side of Earth. For its reason it is stated that since the mass center of Earth is closer to Sun than this part of the fluid and so, it is attracted to Sun more, this fluid lags and so forms this bulge. This reasoning is not complete. For completing it we must consider the circular motion of Earth around Sun. In fact, we can consider each small part of the displacement of Earth around Sun as the vector sum of two displacement: a displacement normal to the radios of orbit of Earth around Sun, and a displacement (at the end of the previous one) toward Sun. Earth gains acceleration only during the second displacement (when being attracted by Sun). This acceleration is in fact the same cause of creation of bulge at the far part of Earth's fluid. This second part of (accelerating) displacement is more dominant in oblong orbit of a comet which can be said nearly is falling to Sun. So, the comet's coma, which is a fluid, will lag more.

For better understanding of the cause of tide we can visualize the solid part of Earth, having a global fluid on itself, in an space free from any gravitation of any other celestial body. Now, suppose that a force is exerted on this set in a manner that every particle of this set gains the same acceleration toward the source of that force. Such an acceleration will not change the global shape of the fluid (and Earth), although the whole set is being accelerated. Now, suppose that the distribution of force is such that the masses closer to the source of force gain more acceleration that masses which are farther. As the result of such a situation, the fluid closer to the force source will become somehow separated from the solid part of Earth. Also, the solid Earth will become somehow separated from the lagging fluid at the opposite side of Earth. These little separations mean that the pressure in the fluid in those parts will decrease. Decrease of the pressure in the fluid causes the new formation of the shape of the fluid such that it can compensate for these decreases in pressure. So, the altitude of the fluid in these parts increases and the bulges will be formed. (We know from hydrostatics that decrease in pressure on a part of a liquid surface causes its rise.) If the mentioned fluid is a gas rather than a liquid, the mentioned separations have this additional effect that the fluctuation of the loosened (or separated) part of the gas aids to its expansion and formation of bulge. So, we have also tide in the atmosphere around Earth, and this causes a part of the winds we have on Earth. Such a gaseous tide is more in a comet's coma.

What presented for the tide caused by Sun's gravitation can be generalized for the tide due to the gravitation of Moon. In fact, Earth and Moon are rotating around their center of mass where is close to the center of Earth. In this rotation, the far fluid of Earth lags and forms the far bulge. Rotation of Earth and Moon around their center of mass is like the rotation of a dumbbell about its center of mass. It is evident that due to the so-called centrifugation, the far fluid will bulge.

What we conclude is that a comet tail is due to the tide caused by Sun's gravitation rather than radiation pressure. If this is the case, we must expect to have a tide or a tail in the part of coma which is closer to Sun. There exists such a tide or tail, and is known as comet's antitail [12-15]. It is probable that in some occasions, antitail acts like a (spike-shaped) hole through which Sun is sucking the comet's coma.

Of course, there exists ion or plasma wind originated from Sun. Such a wind of tiny particles does not have the same strong effect expected for radiation pressure. It seems that we should only count on this wind to propel a solar sail not on what is known as radiation pressure.

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