

Power from Air Ionization

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ABSTRACT: This article aims to investigate the possibility of using atmospheric air ionization in propulsion and energy generation systems. To do this, it is developed a set of equations based on the generation of high-voltage and medium frequency RF electrical fields to ionize the air surrounding a surface and create a differential pressure that produces thrust.

KEYWORDS: atmospheric ionization, ionization energy, Magnus Effect, vacuum trust, differential pressure, propulsion system.

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1 Introduction

Vacuum creation has been known for more than a century by moving the air with mechanical pumps, but with the advent of electromagnetic technologies we have the means to create vacuum with systems based on dissociation and ionization of air. There are several methods to ionize the air: microwave, cathode rays, high-voltage electric fields. All these cause a decrease in the atmospheric pressure on the ionized air region and, therefore, create a pressure difference that

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can be harnessed as thrust force. This technology is relatively simple and can be applied in place of our combustion engines, too old-fashioned for our current ecological needs.

The air ionization system used in the equations of this article is based on high-voltage and medium-frequency electric field generation, widely used by Tesla fans, and the electronics is the same used in inductive heating equipment (recalculating the induction coil and coupling a secondary high voltage coil). In this work we will not develop examples based on other technologies of air dissociation like microwave, cathode rays etc., however, it is certain that those systems will achieve similar results, perhaps with more efficiency. More sophisticated projects, to be used as propulsion in atmospheric transport systems or large electric power plants shall use compatible methods of dissociation and ionization of air.

The principle is that any object normally is subjected to atmospheric pressure in all sides of its surface, so it does not move; therefore, if we lower the atmospheric pressure on one side, there will be a pressure difference between this side and its opposite side, which is able to push the object in the direction where the atmospheric pressure is lower. With an atmospheric pressure of 1.033 kgf/cm², we can create enormous pressure differences, sufficient to build propeller systems that replace those currently available, with the benefit of not being polluting.

This pressure difference is a mechanical energy that is currently used to dimension the vertical lift of aircraft and helicopters. When the aircraft wings or screw-propellers of the helicopters are subjected to a displacement velocity, the upper side thereof has a lower pressure than the lower side. The shape of the wings is such that it produces a difference in air velocity on the upper and lower sides of the wings to establish a low pressure zone on the upper side.

This effect is a statement of Bernoulli's Theorem (Magnus Effect). This theorem states that the laminar flow of air on a surface determines a pressure that is inversely proportional to the square of air velocity:

$$\Delta P = P_1 - P_2 = \frac{1}{2} \rho (v_2^2 - v_1^2) \quad .$$

With:

- P_1 = Pressure on surface 1 [N m⁻²];
- P_2 = Pressure on surface 2 [N m⁻²];
- ΔP = Pressure difference between surfaces [N m⁻²];
- ρ = Density of air at sea level and 15°C = 1.225 kg m⁻³;
- v_1 = Air flow velocity on surface 1 [m s⁻¹];
- v_2 = Air flow velocity on surface 2 [m s⁻¹].

Assuming that we can boost the air at the speed of 300 m/s, we will have:

$$\Delta P = \frac{1}{2} \rho (v_2^2 - v_1^2) = \frac{1}{2} * 1.225 * ((3 * 10^2)^2 - 0) = 5.513 * 10^4 \text{ N m}^{-2} = 0.562 \text{ kgf cm}^{-2} \quad .$$

This pressure difference, which is very close to ½ atmosphere, provides the vertical lift of the aircraft, sizing the area of the wings to get an upward force that compensates the weight of the aircraft. However, it is possible to create a pressure difference with various air ionization processes currently available. By ionizing the atmospheric air we can create a low pressure zone to get a thrust force. Such method can be applied to any suitably designed surface, including for lifting and propulsion of atmospheric crafts, as described in the text below extracted from the book² Contact with the Flying Discs[1]:

2 In searching new forms of energy and propulsion systems we can and must consider all the available literature, including those weird and doubtful. Studying these and using our understanding we can acquire knowledge beyond that currently established. It is not wise to discard alternative information based upon the established knowledge.

Question – Is there any inconvenience in clearing us up about problems with flying saucers?

Answer – Absolutely, none. Of course, an interplanetary journey would still take a lot of time for the people of Earth, but let's give them a helping hand, showing you how things happen:

The atmospheric weight of the Earth is 1.033 kgf/cm². If we put a sheet of paper in the mouth of a glass filled with water, face down, the atmospheric pressure exerted from below upwards will prevent the water from suffering gravity and fall.

With the flying saucer we use this natural force of the atmosphere. It is she who gives us the necessary propulsion. If on the lower part of the disk we maintain this pressure and cause a decompression in the upper part, the device will undergo a fabulous upward thrust, with a power that no known force can match.

Q – Please, do you want to be more explicit? I'm not fully understanding the system as you describe it.

A – It's simple, my friend. We make the vacuum in the direction we want to go. If we have low pressure on one side, on the other we get the atmospheric pressure integrally. Any device, whatever it may be, can only be moved by obtaining a potential difference. For example, on a disc with 20 meters in diameter, we have a surface area = $\pi r^2 = \pi 10^2 = 314.16 m^2$.

Considering now that the atmospheric pressure is equal to 1.033 kgf/cm² (1,053.01 N/m²), we conclude that the force acting on the disk is 3,245,272.8 kgf, when its dimensions correspond to 20 meters in diameter.

$$F = P S = 1.033 * 3.1416 * 10^6 = 3.245 * 10^6 \text{ kgf} = 3.183 * 10^7 \text{ N}$$

To give you an idea of what that means, imagine that on a smallest disc we have a thrust of three million kilograms, while the most powerful terrestrial airplanes do not exceed a few thousand kilograms.

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When we make interplanetary trips, we use small capacity devices. It depends on the end we have in view. Usually 20-meter disks are convenient. These fully equipped appliances weigh a maximum of 250,000 kilograms. We also have a margin of three million kilograms, which we use for high speeds. No one would ever get such energy on a ship. Not even atomic energy could match the forces of nature. And that without poisoning the atmosphere. Did you understand well, now?

Q – I understood. It's amazing how easy the process is!

A – Yes, it's easy. It is the egg of Columbus. But it would be incomplete if I refused to say what medium we use to make the vacuum externally. First let me explain to you the steering system:

We can transfer that vacuum to any direction. With a simple lever in a hemisphere we transfer it to where we want to go. If we want to go to one side, we provoke the vacuum to it, and immediately the atmosphere exerts pressure in that direction. Let's say: we are flying in the horizontal plane. If we want to make a 90 degree angle, we just have to transfer the vacuum up or to one side, and we will go with the same speed in that direction. It does not need a curve. Do you understand?

Q – Yes, I saw the whole range. This can revolutionize everything we know about navigation. It is a diabolical device.

A – It depends on the use you make. I still believe in the kindness of the man and I promise, if one day they promise us to end the wars, come personally and help them reach that desideratum. Not only that, but more superior things. I will teach you how to make life a paradise.

But as we were saying, we get a vacuum and a pressure, as you say, diabolical. We have, however, no friction, since for the direction we are going there is only the vacuum. Therefore, without friction, the appliance does not heat up. We often lack even a little warmth to maintain

ourselves, because the temperature is too low.

As for the process of making the vacuum externally, there is no technical difficulty whatsoever. You know that cathode rays have the strange property of decomposing the atmosphere they pass through. The atmospheric elements, under the action of these rays, return to the ethereal state. To this property, we have added that of causing the cathode rays to cross with the anodic rays at a 45 degree angle. This is done by employing high voltage and amperage.

Q – Where is the cathode ray emitter located?

R – Throughout the peripheral zone of the disc. That is to say, the entire lateral part of the apparatus is a tube of rays, between two walls. These rays are deadly and can only be projected to the outside. A human being who received the emission of the cathode rays with the intensity that we use would have all the globules destroyed and would suffer mortal burns. But inside the device there is less radioactivity than the air you breathe on Earth.

The color you see is the consequence of these rays, as in a tube of Crooks and Geissler. It depends on the low pressure we get, that is, the vacuum. If we want to go fast, we make the absolute vacuum and become a ray in space; if not, we do semi-vacuum, and let's go slow. The vacuum intensity is achieved by the amperage used, using a rheostat. If we want to float, we use a weak current.

When we are in semi-vacuum, you see luminosity at night; but if we are using absolute vacuum, no one sees us because there is no light in the vacuum³. That's why they always say that we stand, and suddenly we disappear and appear elsewhere.

Ionizing the atmospheric air creates a region of lower pressure because the produced ions are absorbed by the electrostatic field of the atmosphere, that is, positive ions are drained to the ground where the electric potential is negative, and negative ions are drained to the high atmospheric layers where the electric potential is highly positive. This work is done by the electrostatic field of the atmosphere created by cosmic rays and solar radiation that reaches the Earth.

But we are interested in energy generation too. Would it be possible that the energy spent in the process of dissociation and ionization of atmospheric air would be less than the mechanical energy available? The following text, taken from the same book[1], indicates this possibility:

The energy of the apparatus can be extracted from the atmosphere itself, which would give it a continuous movement, without any interruption.

We have seen that it is not the ionic movement that produces the vacuum but rather the absorption that the atmosphere exerts on the ions, according to the electric potential of the atmosphere. This potential is so great that with every 1 meter of elevation of a coated wire and with the tip heated, one obtains from 60 to 600 Volts. The energy used to produce the vacuum is less than the effect obtained by atmospheric pressure.

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Many people who saw discs could observe that they (not all) have a central hole made up of a tube. Inside there is an air-driven turbine.

If the enough force to move a 20 meters disc in diameter was a pressure of about 300,000 kgf/cm², and if that pressure exceeds 3,000,000 kgf/cm², there would be a tremendous waste energy. By opening a gate, the compressed air on one side of the disc is thrown into the vacuum zone, creating a powerful air current that will drive the turbine blades. In an air tunnel 4 meters in diameter, the pressure on the blades of the turbine would be equal to 130 tons, that is, the pressure of a jet of water of 1 square meter by 130 meters in height. The current of air produced would be so great that a man could be sucked 10 meters away. If a disk, running its turbine, passes over a

³ The light disappears from the cathode ray tubes, if inside we decrease the pressure. Therefore, light is an atmospheric effect, and we would live in the dark if we could inhabit the vacuum.

tree, the atmospheric movement would smash its branches. The energy thus obtained would be enough to keep a few dozen large industries running.

From what is known, this is how the inhabitants of other planets capture the electric energy they need, without making use of the waterfalls that, for them, are adornments of nature.

The air that penetrates from one side exits to the zone of the vacuum, which is immediately ionized and absorbed by the atmosphere. There is, therefore, always a small atmospheric layer near the disc. The instant the device wants to brake, the emission of Lenard rays decreases and this atmospheric layer gradually increases until it joins the adjacent atmosphere. If the shock of the particles are too violent, this will be done away from the apparatus, with complete protection of the structure.

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It turns out that the effect is often superior to the cause. By adding chlorine to the water, a small ray of light is sufficient to detonate the mixture and convert into energy. The simple energy of a percussor in the detonator sends a ballistic projectile miles away.

The same goes for the endless energy of a disk. Atmospheric ionization on one side results in fabulous pressure on the other. It is the percussor that triggers a hurricane in the rear of the disc.

These texts invite us to search mathematical methods to estimate the electrical energy needed to ionize the air and the mechanical energy available. In this work, we will consider that the pressure reduction is performed in one side of metallic boards through the dissociation and ionization of the atmospheric air with the application of electric fields of high-voltage and medium frequency. It can be realized with the technology developed by Nicola Tesla with its resonant high-voltage generators, although there is no need to be resonant, and with induction heating equipment that has a calculated high-voltage secondary coil coupled with a recalculated primary coil.

What is the amount of energy needed to dissociate and ionize atmospheric air? What level of dissociation do we need? Is it sufficient to separate the ions from the lighter gases or is it necessary to dissociate so intensely that the gases return to the immaterial or ethereal state? This article intends to study these possibilities.

2 The Atmosphere that Surrounds the Earth

The diameter of the planetary sphere is estimated in 13,000 km and its perimeter is approximately 40,000 km. The atmosphere is formed by five successive layers, each with its own characteristics:

1. Troposphere:

It is the layer of air that goes from the ground up to approximately 12 km. The air in this layer contains dust and gaseous pollutants. The winds, the clouds, the snow and the rain form in this layer, where also happens the storms, the thunderstorms and the lightning.

2. Stratosphere:

This layer begins when the troposphere ends and reaches 50 km of altitude. The air is rarefied and the temperature is on average -50°C . The stratosphere contains the ozone gas that serves to filter the ultraviolet rays that arrive to the Earth, functioning as a true filter.

3. Mesosphere:

This layer extends from 50 km up to approximately 80 km altitude. The temperature reaches -120°C .

4. Thermosphere:

This layer reaches about 640 km above the earth's surface. Its temperature is about $1,000^{\circ}\text{C}$. In this region occurs the northern lights (aurora borealis) and southern lights (aurora australis).

5. Exosphere:

It is the last layer, where the air is extremely rarefied and starts at a latitude of about 500 km and goes up to over 1,000 km. The predominant gas is hydrogen. The temperature, during the day, exceeds 2,000° C; at night, the temperature drops to about -270° C

2.1 Composition of the Atmosphere

The first layer of the atmosphere called troposphere contains about 80% of the total mass of gases in the atmosphere. The second layer called stratosphere contains about 19.9% of the total mass and very little water vapor. Therefore, in the first two layers is almost the entire mass of the atmosphere, or 99.9% of the total. The table below shows the volumetric percentages of the main components of dry air.

Gas	Volumetric proportion [%]
Argon (Ar)	0.93
Krypton (Kr)	0.0001
Carbon dioxide (CO ₂)	0.036
Helium (He)	0.0005
Hydrogen (H ₂)	0.00005
Neon (Ne)	0.0018
Nitrogen (N ₂)	78.08
Methane (CH ₄)	0.00017
Nitrous oxide (N ₂ O)	0.00003
Oxygen (O ₂)	20.95
Ozone (O ₃)	0.000004
Xenon (Xe)	0.000001

The gases of greatest abundance in the atmosphere are Nitrogen (78.08%) and Oxygen (20.95%), which add up to 99.03% of the atmospheric volume, so our interest is concentrated in the dissociation and ionization of these two gases. Water vapor is not listed but is an important component. The ratio is variable depending on the location and other conditions and may reach up to about 4%.

2.2 Electrostatic Field of the Atmosphere

The earth is constantly bombarded by radiation from outer space that interacts with atoms in the atmosphere to create a scattering of secondary ionizing radiation that ensures that the atmosphere is weakly conductive and constantly charged with new ions. This way, the earth with its atmosphere looks like a charged spherical capacitor.

The total potential difference from the surface of the earth to the top of the atmosphere is about 400,000 Volts. The air above the surface is positively charged, while the earth's surface charge is negative. But because the air is not a perfect insulator, there is an electric current density continuously flowing to the earth's surface of only 10^{-12} A/m², that adds up to 1,800 A at any time, considering the total surface of the earth. That is a power of 700 MW.[2]

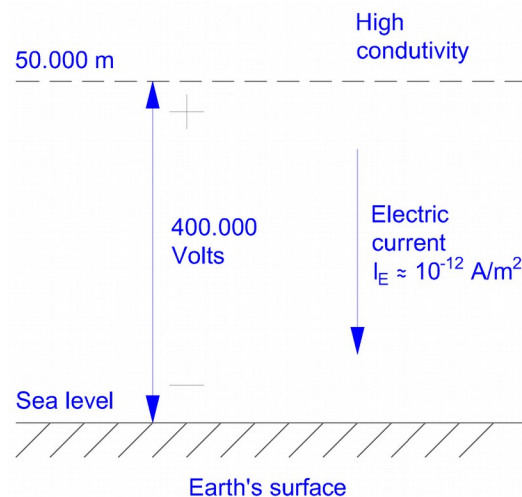


Figure 1: Atmospheric electric potential.

To measure the electrostatic potential of the atmosphere it is often used to heat metal tips at high temperatures to ionize the surrounding air and make it conductive. At sea level up to 1 m in height this voltage varies from 80 to 180 Volts, depending on solar incidence, relative humidity of air, composition of atmospheric gases etc.; at higher altitudes, the potential difference also increases, so that if heated metal tips are positioned between 100 and 101 m in height, it can reach 300 Volts, the positive pole being at 101 m and the negative pole being at 100 m.

The distribution of these charges into the atmosphere provides a volumetric density of electrostatic charges that varies with altitude. The electron density of atmospheric air, at sea level where the pressure is 1 atmosphere, is $4 \cdot 10^{25}$ electrons/m³. At the pressure of 1 atmosphere and temperature of 300 K there are approximately $2.447 \cdot 10^{25}$ molecules or atoms of gases per m³. The relationship between the pressure and the atomic density of the atmosphere at the temperature of 300 K is:

$$n_0 = 3.220 \cdot 10^{22} P_{[mmHg]} = 2.447 \cdot 10^{25} P_{[atm]} = 2.415 \cdot 10^{20} P_{[N/m^2]} .$$

With:

$$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mmHg} = 1.033 \text{ kgf cm}^{-2} = 1.01325 \cdot 10^5 \text{ N m}^{-2};$$

$$n_0 = \text{Density of atoms in the atmosphere [atoms m}^{-3}\text{];}$$

$$P_{[atm]} = \text{Atmospheric pressure [atm];}$$

$$P_{[N/m^2]} = \text{Atmospheric pressure [N m}^{-2}\text{].}$$

The above formula is derived from the law that determines the atomic density of the perfect gases:

$$PV = N k_B T = n RT \quad \text{and} \quad R = N_A k_B .$$

With:

$$P = \text{Gas pressure [N m}^{-2}\text{];}$$

$$V = \text{Gas volume [m}^3\text{];}$$

$$N = \text{Quantity of gas molecules [molecules];}$$

$$k_B = \text{Boltzmann's constant} = 1.3806503 \cdot 10^{-23} \text{ J K}^{-1} = 8.6173324 \cdot 10^{-5} \text{ eV K}^{-1};$$

$$n = \text{Quantity of gas moles [mol];}$$

$$R = \text{Constant of perfect gases} = 8.3144621 \text{ J mol}^{-1} \text{ K}^{-1};$$

$$N_A = \text{Avogadro's number} = 6.0221413 \cdot 10^{23} \text{ molecules mol}^{-1};$$

$$T = \text{Gas temperature [K].}$$

The collision frequency of electrons and ions in air varies with temperature and altitude: at sea level, where the pressure is 760 mmHg, it is $4.66 \cdot 10^{11}$ collisions/s. The table below shows the frequency variation of electron collisions in the air as a function of the altitude above the surface of the earth for three ambient temperatures.[3]

Altitude [km]	Pressure [mmHg]	Pressure [atm]	Pressure [N/m ²]	T = 300 K [collisions/s]	T = 500 K [collisions/s]	T = 1000 K [collisions/s]
0	760	1.000	$1.013 \cdot 10^5$	$4.66 \cdot 10^{11}$	$4.17 \cdot 10^{11}$	$4.25 \cdot 10^{11}$
3.44	500	$6.579 \cdot 10^{-1}$	$6.667 \cdot 10^4$	$1.03 \cdot 10^{11}$	$1.21 \cdot 10^{11}$	$1.80 \cdot 10^{11}$
10.0	200	$2.632 \cdot 10^{-1}$	$2.667 \cdot 10^4$	$2.36 \cdot 10^{10}$	$3.67 \cdot 10^{10}$	$7.20 \cdot 10^{10}$
14.5	100	$1.316 \cdot 10^{-1}$	$1.333 \cdot 10^4$	$1.21 \cdot 10^{10}$	$1.93 \cdot 10^{10}$	$3.71 \cdot 10^{10}$
18.9	50	$6.579 \cdot 10^{-2}$	$6.667 \cdot 10^3$	$6.07 \cdot 10^9$	$9.70 \cdot 10^9$	$1.86 \cdot 10^{10}$
24.8	20	$2.632 \cdot 10^{-2}$	$2.667 \cdot 10^3$	$2.38 \cdot 10^9$	$3.00 \cdot 10^9$	$7.27 \cdot 10^9$
29.4	10	$1.316 \cdot 10^{-2}$	$1.333 \cdot 10^3$	$1.18 \cdot 10^9$	$1.87 \cdot 10^9$	$3.57 \cdot 10^9$
34.0	5	$6.579 \cdot 10^{-3}$	$6.667 \cdot 10^2$	$5.84 \cdot 10^8$	$9.14 \cdot 10^8$	$1.73 \cdot 10^9$
40.7	2	$2.632 \cdot 10^{-3}$	$2.667 \cdot 10^2$	$2.72 \cdot 10^8$	$3.82 \cdot 10^8$	$6.72 \cdot 10^8$

Altitude [km]	Pressure [mmHg]	Pressure [atm]	Pressure [N/m ²]	T = 300 K [collisions/s]	T = 500 K [collisions/s]	T = 1000 K [collisions/s]
45.9	1	$1.316 \cdot 10^{-3}$	$1.333 \cdot 10^2$	$2.15 \cdot 10^8$	$2.48 \cdot 10^8$	$3.65 \cdot 10^8$
51.5	0.5	$6.579 \cdot 10^{-4}$	$6.667 \cdot 10^1$	$1.22 \cdot 10^8$	$1.34 \cdot 10^8$	$1.89 \cdot 10^8$
58.6	0.2	$2.632 \cdot 10^{-4}$	$2.667 \cdot 10^1$	$2.67 \cdot 10^7$	$3.78 \cdot 10^7$	$6.71 \cdot 10^7$
63.7	0.1	$1.316 \cdot 10^{-4}$	$1.333 \cdot 10^1$	$1.18 \cdot 10^7$	$1.83 \cdot 10^7$	$3.44 \cdot 10^7$
68.7	$5 \cdot 10^{-2}$	$6.579 \cdot 10^{-5}$	6.667	$5.92 \cdot 10^6$	$9.42 \cdot 10^6$	$1.80 \cdot 10^7$
74.7	$2 \cdot 10^{-2}$	$2.632 \cdot 10^{-5}$	2.667	$2.49 \cdot 10^6$	$3.98 \cdot 10^6$	$7.64 \cdot 10^6$
77.3	$1 \cdot 10^{-2}$	$1.316 \cdot 10^{-5}$	1.333	$1.27 \cdot 10^6$	$2.03 \cdot 10^6$	$3.89 \cdot 10^6$
83.5	$5 \cdot 10^{-3}$	$6.579 \cdot 10^{-6}$	$6.667 \cdot 10^{-1}$	$6.62 \cdot 10^5$	$1.06 \cdot 10^6$	$2.03 \cdot 10^6$
88.7	$2 \cdot 10^{-3}$	$2.632 \cdot 10^{-6}$	$2.667 \cdot 10^{-1}$	$2.57 \cdot 10^5$	$4.11 \cdot 10^5$	$7.89 \cdot 10^5$
91.4	$1.32 \cdot 10^{-3}$	$1.737 \cdot 10^{-6}$	$1.760 \cdot 10^{-1}$	$1.61 \cdot 10^5$	$2.58 \cdot 10^5$	$4.94 \cdot 10^5$

3 Atmospheric Air Ionization

The atmosphere surrounding the planet's surface is made up of a mixture of gases that, in the normal state, behaves like an electrical insulator. It is necessary to induce the formation of ions so that these gases become conductive and exhibit the same effects as observed in low pressure electronic tubes.

Friedrich Paschen studied the breakdown voltage of various gases between parallel metal plates as consequence of the gas pressure and gap distance of the electrodes. With a constant gap length, it was observed that, due to the lowering of the pressure inside these tubes, the voltages involved in the transport of ions, electrons and protons are directly proportional to the pressure, until the rarefaction of the air prevents the formation of ions and, from this point on, the voltages become inversely proportional to the pressure.

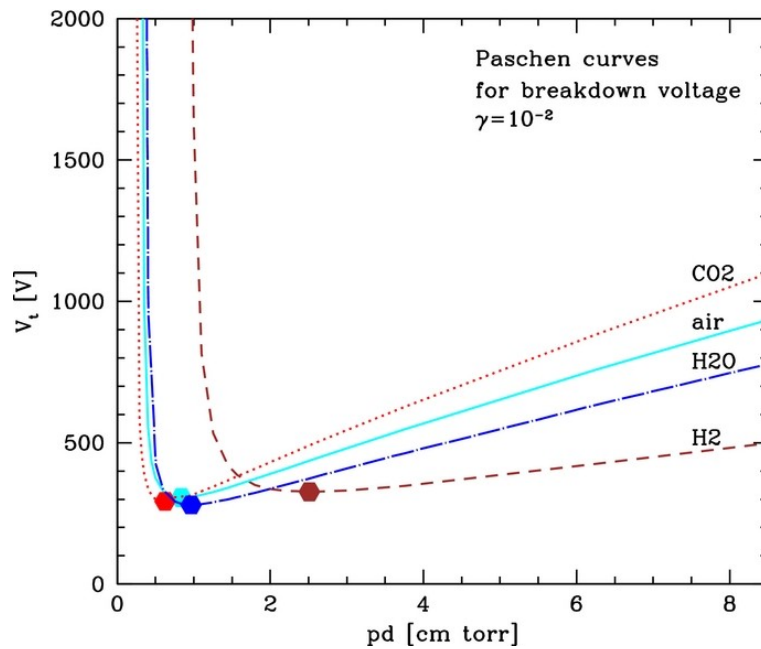


Figure 2: Paschen's curves for CO_2 , air, H_2O and H_2 .

The same phenomena occurs with atmospheric air when subjected to the action of increasing electrical voltages. The Paschen's curves above show that the breakdown voltage V_t of a capacitor depends on the material of the cathodes (characterized by Townsend's 2nd ionization

coefficient γ), the type of gas between the capacitor plates, and the product of gas pressure p and the capacitor plate separation d . [4]

At the end of the 19th century, Nicola Tesla carried out numerous tests with low, medium and high frequency high-voltage generator systems, so he developed lighting systems in evacuated tubes. In his tests, Nicola Tesla discovered that the atmosphere subjected to high voltages (hundreds of kVolts to tens of MVolts) and variable frequencies (tens of kHz to tens of MHz) behaved differently from the normal state – despite being under ambient pressure, air could suffer the same effects as rarefied air tubes.

He also observed that the use of medium-frequencies (several hundred kHz) favored the corona effect and reduced electric discharges. In this way, the air became luminous and conductive, allowing the passage of electric current between two wires apart and connected to the secondary terminals of a high-voltage transformer. However, even with a single wire connected to the output of the secondary, the phenomenon of luminosity (corona) also occurred.

Air at atmospheric pressure has a higher density (molecules/m³) than an evacuated tube and requires more energy to ionize. During air ionization, the medium-frequency is necessary to prevent ions from traveling directly between the two high-voltage terminals or between a terminal and ground, to avoid electric discharges. These ions are constantly attracted to the pole of opposite polarity, tending to move to two opposite paths in the frequency of oscillations.

In this situation, the high voltage determines the production of ions, as well as their acceleration, and the frequency establishes the constant inversion of the ions direction and the increase of collisions between ions and molecules. There is a compromise between the applied electric voltage between two plates, the distance between them and the frequency of the electric field that allows the formation of the corona effect, that is a partial ionization, and the ionization needed to reduce the atmospheric pressure to produce thrust.

If we have two insulated plates, separated from each other and connected to the two high-voltage Tesla secondary terminals, we can observe the following: the higher the electric voltage, the greater the acceleration of the ions and the greater the ionization of the air; the closer the plates are to each other, the faster the ions reach the opposite plate, so the chance to occur discharges is higher; the higher the frequency, the lower the chance of the ions reaching the opposite plate and the greater the ionization.

The ionization effect is precisely what is necessary for the surrounding neutral atmosphere to absorb the ions created in the air ionization process. An area of low pressure is created because the ions do not remain in the site where they are produced, they are removed by the atmospheric electrostatic field. The absorption of these ions occurs as a consequence of the displacement caused by the force that an electric field cause on electric charges. It is the electrostatic field of the atmosphere that carries out the work of displacing the ions:

- Positive ions are attracted to ground;
- Negative ions are attracted to high atmospheric layers.

So, the vast energy stored in the electrostatic field of the atmosphere can realize work for us, and we only need to ionize the air.

3.1 Dissociation and Ionization Energy of Gases

When radiations collide with gases in the atmosphere, cause chemical effects that are manifested in the breakdown of chemical bonds between the atoms that make up the molecules and produce atomic ionization. The chemical reactions triggered by the action of radiation are called photochemical reactions or photolysis. The photochemical reactions that lead to the rupture of bonds are molecule dissociation, from which free radicals result. Each molecule, to dissociate, needs a minimum energy value, called dissociation energy.

The most abundant gases in the atmosphere are nitrogen and oxygen, which account for 99.03% of the total, so our interest is concentrated in the dissociation and ionization of these two gases. Below are the dissociation and ionization tables of these gases, where $1 \text{ eV} = 1.602 \cdot 10^{-19} \text{ J}$.

If the incident radiation has energy equal to the dissociation energy of the molecule, the molecule separates into free radicals that have no kinetic energy; if the incident radiation has higher energy than the energy of dissociation, the molecule separates into free radicals and the excess energy provides kinetic energy for the particles, which translates into an increase in temperature of the region. If the incident radiation has lower energy, the energy is absorbed and only the thermal effect occurs because the kinetic energy of the molecule increases.

Molecule	Dissociation	Dissociation Energy
N_2	$\text{N}_2 + hf \rightarrow \text{N} + \text{N}$	$10.0 \text{ eV} = 1.60 \cdot 10^{-18} \text{ J}$
O_2	$\text{O}_2 + hf \rightarrow \text{O} + \text{O}$	$5.2 \text{ eV} = 8.3 \cdot 10^{-19} \text{ J}$

If the radiation energy is equal to or greater than the minimum removal energy of the outermost electron, the radiation ionizes the particle. If there is an ionization, the energy absorbed by the particles is used to remove an electron, with each particle having a +1 electric charge. This minimum removal energy is called 1st ionization energy (E_1) or 1st ionization potential; it is the required energy to remove an electron from a neutral atom in the gaseous phase.

Molecule/Atom	Ionization	1 st Ionization Energy
N_2	$\text{N}_2 + hf \rightarrow \text{N}_2^+ + e^-$	$14.53414 \text{ eV} = 2.3286 \cdot 10^{-18} \text{ J}$
N	$\text{N} + hf \rightarrow \text{N}^+ + e^-$	$14.4 \text{ eV} = 2.31 \cdot 10^{-18} \text{ J}$
O_2	$\text{O}_2 + hf \rightarrow \text{O}_2^+ + e^-$	$13.61806 \text{ eV} = 2.1819 \cdot 10^{-18} \text{ J}$
O	$\text{O} + hf \rightarrow \text{O}^+ + e^-$	$11.9 \text{ eV} = 1.91 \cdot 10^{-18} \text{ J}$

If the incident radiation has higher energy than the ionization energy of the particle, the excess energy provides kinetic energy for the ions. If the incident radiation has lower energy, the energy is absorbed and the particle gets excited, there is a thermal effect where the kinetic energy of the particle increases and/or it loses the energy through the emission of photons.

3.2 Ionization Energy of Atmospheric Air

With the energies of dissociation and ionization of the molecules and atoms of nitrogen and oxygen and their volumetric proportions in the atmospheric air, we can estimate the amount of energy necessary to ionize a determined volume of air. Thus, 1 m^3 of air, which corresponds to 1,000 liters, contains approximately 780.8 liters (78.08%) of nitrogen molecules (N_2) and 209.5 liters (20.95%) of oxygen (O_2) molecules.

One mole of a gas, under normal conditions of temperature and pressure (NTP), occupies a volume of 22.41 liters, so in 1 m^3 of atmospheric air (1,000 liters) we will have:

- Nitrogen:
 78.08% of 1,000 liters = 780.8 liters/ m^3 ;
 $(780.8 \text{ liters}/\text{m}^3) / (22.41 \text{ liters}/\text{mole}) = 34.86 \text{ moles}/\text{m}^3$.
- Oxygen:
 20.95% of 1,000 liters = 209.5 liters/ m^3 ;
 $(209.5 \text{ liters}/\text{m}^3) / (22.41 \text{ liters}/\text{mole}) = 9.353 \text{ moles}/\text{m}^3$.

One mole of a gas contains $6.022 \cdot 10^{23}$ molecules, so in 1 m^3 of atmospheric air we will have:

- Nitrogen:
 $(34.86 \text{ moles}/\text{m}^3) \cdot (6.022 \cdot 10^{23} \text{ molecules}/\text{mole}) = 2.099 \cdot 10^{25} \text{ molecules}/\text{m}^3$;

2. Oxygen:
(9.353 moles/m³)*(6.022*10²³ molecules/mole) = 5.632*10²⁴ molecules/m³;
3. Total: 2.662*10²⁵ molecules/m³.

The total value of the molecule density calculated above is close to the tabulated value of the gas molecule density of the atmosphere at sea level, which is $n_0 = 2.447*10^{25}$ molecules/m³. Knowing the energies of 1st ionization of these molecules, we can estimate the amount of energy needed to ionize 1 m³ of atmospheric air at NTP, therefore:

$$u_T = E_{1N} n_N + E_{1O} n_O \quad ,$$

$$u_T = 2.3286 * 10^{-18} * 2.099 * 10^{25} + 2.1819 * 10^{-18} * 5.632 * 10^{24} = 6.117 * 10^7 \text{ J m}^{-3} \quad .$$

With:

- u_T = Volumetric density of air ionization energy [J m⁻³];
- E_{1N} = 1st ionization energy of the nitrogen molecule [J];
- n_N = Number of nitrogen molecules per m³ of air [molecules m⁻³];
- E_{1O} = 1st ionization energy of the oxygen molecule [J];
- n_O = Number of oxygen molecules per m³ of air [molecules m⁻³];

With this ionization energy we will have reached 99.03% ionization of atmospheric air at sea level, which means almost absolute vacuum. In an open device where air can be introduced, this energy must be constantly expended to maintain the required dissociation rate. However, this dissociation rate is the maximum allowed in a thrust system, so this is the maximum energy required to cause maximum ionization.

In a physical device, where the rate of ionization varies as needed, lower energy values will be used when less thrust is needed. Knowing that the volumetric density of molecules varies with the atmospheric pressure in the ratio $n_0 = 2.447 * 10^{25} P_{[atm]} = 2.415 * 10^{20} P_{[N/m^2]}$ and the relation between units of pressure measurement [atm] and [N m⁻²] is $P_{[N/m^2]} = 1.01325 * 10^5 P_{[atm]}$, the amount of energy spent to dissociate and ionize the air with a pressure lower than 1 atm will be equated by:

$$u = u_T \Delta P = (E_{1N} n_N + E_{1O} n_O) \Delta P = 6.117 * 10^7 \Delta P_{[atm]} = 6.037 * 10^2 \Delta P_{[N/m^2]} \quad .$$

With:

- u = Volumetric density of air ionization energy [J m⁻³];
- ΔP = Air pressure difference;
- $\Delta P_{[atm]}$ = Air pressure difference [atm];
- $\Delta P_{[N/m^2]}$ = Air pressure difference [N m⁻²].

In the high layers of the atmosphere, where the density of air molecules is smaller, the energy spent in the ionization process will be proportionally smaller, but as the atmospheric pressure is also lower, there will be less thrust. Therefore, we will have to ionize a larger amount of gases to compensate for this difference, and in the end, for a given pressure difference we will have to use a proportional ionization energy.

3.3 Ionization Power of Atmospheric Air

In a device that uses electric fields to ionize, as long as the air is ionized, there will be an energy expenditure proportional to the amount of ions produced, so an electric power will be associated with the process. The total ionization of 1 m³ of air at 1 atm produces 2.662*10²⁵ negative ions and 2.662*10²⁵ positive ions and, if this quantity of ions is produced in every 1 second, we will have used a power of:

$$P_{m3} = \frac{d u_T}{dt} = 6.117 * 10^7 \Delta P_{[atm]} = 6.037 * 10^2 \Delta P_{[N/m^2]} .$$

With:

P_{m3} = Volumetric density of air ionization power [W m⁻³];
 u_T = Volumetric density of air ionization energy [J m⁻³];
 t = Time [s].

If $\Delta P_{[atm]} = 1$ atm, this is the power required to fully ionize 1 m³ of air in one second, this is, create a vacuum in 1 m³ of air. If $\Delta P_{[atm]} < 1$ atm, the required energy will be proportional to this reduction of atmospheric pressure. In an ionization device where air can enter freely, the volume of ionized air is determined by the area of the ionization chamber and the displacement velocity of the air flowing into it, thus:

$$P = u A v , \quad u = 6.117 * 10^7 \Delta P_{[atm]} = 6.037 * 10^2 \Delta P_{[N/m^2]} .$$

With:

P = Ionization electric power [W];
 u = Volumetric density of air ionization energy [J m⁻³];
 A = Area of the ionization chamber [m²];
 v = Air inlet velocity [m s⁻¹];
 ΔP = Air pressure difference [atm] [N m⁻²].

The displacement velocity of the air entering the chamber is determined by the pressure difference between the inside and outside of the chamber, caused by the air ionization process. To estimate the power used in the air ionization process inside an ionization chamber, it is necessary to estimate the air inlet velocity and calculate the volume of ionized air in the unit of time.

We will use the Bernoulli equation (magnus effect) to estimate the air inlet velocity in the ionization chamber as a function of the pressure difference between the external side and the inner side of the chamber. The equation states that the flow of a fluid inside a horizontal tube determines a pressure that is inversely proportional to the square of its velocity. If this tube is tilted, it will be necessary to consider the difference in mechanical potential energy. Thus, Bernoulli's complete equation:[5]

$$P_1 + \rho g h_1 + \rho \frac{v_1^2}{2} = P_2 + \rho g h_2 + \rho \frac{v_2^2}{2} .$$

With:

P_1 = Pressure at point 1 [N m⁻²];
 h_1 = Height at point 1 [m];
 v_1 = Flow rate of fluid at point 1 [m s⁻¹];
 P_2 = Pressure at point 2 [N m⁻²];
 h_2 = Height at point 2 [m];
 v_2 = Flow rate of fluid at point 2 [m s⁻¹];
 ρ = Volumetric mass density or specific mass of the fluid [kg m⁻³];
 g = Gravity acceleration [m s⁻²].

In a horizontal flow, which is our situation under study, there is no difference in height, therefore, the equation sums up to:

$$P_1 + \rho \frac{v_1^2}{2} = P_2 + \rho \frac{v_2^2}{2} .$$

Isolating the pressure terms of the equation, we have:

$$\Delta P = P_1 - P_2 = \frac{1}{2} \rho (v_2^2 - v_1^2) .$$

For our estimates, we will consider that the ionization chamber is located in an environment where the air is stationary, so the initial velocity of the air is zero. Isolating the final velocity, we have:

$$v = \sqrt{\frac{2 \Delta P_{[N/m^2]}}{\rho}} .$$

If we establish a pressure difference of $\frac{1}{4}$ atmosphere between the inside and outside of the chamber, we will have a displacement velocity of air entering the chamber:

$$v = \sqrt{\frac{2 \Delta P_{[N/m^2]}}{\rho}} = \sqrt{\frac{2 * 2.533 * 10^4}{1.225}} = 203.4 \text{ m s}^{-1} .$$

With:

v = Air velocity [m s^{-1}];

$\Delta P_{[N/m^2]}$ = Air pressure difference = $\frac{1}{4} * 1.01325 * 10^5 \text{ N m}^{-2} = 2.533 * 10^4 \text{ N m}^{-2}$;

ρ = Air specific mass at sea level and $15^\circ\text{C} = 1.225 \text{ kg m}^{-3}$.

With this information and knowing that the total ionization electric power is $P = u S v$, we can estimate the surface power density spent in the air ionization process considering only the pressure difference:

$$P_{m2} = \frac{P}{S} = u v = u \sqrt{\frac{2 \Delta P_{[N/m^2]}}{\rho}} .$$

With:

P_{m2} = Surface power density [W m^{-2}];

P = Ionization electric power [W];

S = Area of the ionization chamber [m^2];

u = Volumetric density of air ionization energy [J m^{-3}];

v = Air inlet velocity [m s^{-1}].

As an example, the necessary surface power density to establish a pressure difference of $\frac{1}{4}$ atmosphere between the inside and outside of the chamber, with the volumetric density of air ionization energy already calculated of $u = 6.117 * 10^7 * \Delta P_{[atm]} [\text{J m}^{-3}]$, is:

$$P_{m2} = u \sqrt{\frac{2 \Delta P_{[N/m^2]}}{\rho}} = 6.117 * 10^7 \frac{1}{4} \sqrt{\frac{2 * 2.533 * 10^4}{1.225}} = 3.110 * 10^9 \text{ W m}^{-2} .$$

Knowing the surface area of the ionization chamber, we can estimate the total electric power spent to maintain a pressure difference between inside and outside of the chamber:

$$P = P_{m2} S = u v S = u S \sqrt{\frac{2 \Delta P}{\rho}} .$$

As an example, we will calculate the power required to maintain a pressure difference of $\frac{1}{2}$ atmosphere in an ionization chamber with 30 cm^2 of surface area.

$$P = u S \sqrt{\frac{2 \Delta P_{[N/m^2]}}{\rho}} = 6.117 * 10^7 \frac{1}{2} 3 * 10^{-3} \sqrt{\frac{2 * 5.067 * 10^4}{1.225}} = 2.639 * 10^7 \text{ W}$$

Under the above conditions, the air will enter the chamber at a speed of 287.6 m/s. The air flow, which is the volume of ionized air per second, is given by:

$$V_{air/s} = S v = S \sqrt{\frac{2 \Delta P}{\rho}} = 3 * 10^{-3} * \sqrt{\frac{2 * 5.067 * 10^4}{1.225}} = 0.8629 \text{ m}^3 \text{ s}^{-1} .$$

As we see, in order to maintain a pressure difference of $\frac{1}{2}$ atmosphere between the inner and outer sides of this ionization chamber, it is necessary to ionize 862.9 liters of air per second. With this volume and the power needed to ionize it we may confirm that this is the correct volumetric density of air ionization energy:

$$u = \frac{P}{V_{air/s}} = \frac{2.639 * 10^7}{0.8629} = 3.058 * 10^7 \text{ J m}^{-3} .$$

This is half the volumetric density of air ionization energy needed to totally ionize this volume, so this half energy density value ionizes this volume up to $\frac{1}{2}$ atmosphere.

4 Atmospheric Plasma

For industrial plasma applications, electric fields of Radio Frequency (RF) capacitively coupled to the plasma reactor produce the corona effect. To produce the corona discharge in the air at NTP (Normal Temperature and Pressure – 20°C and 1 atm) it is not necessary to reach the break point of the air dielectric, which is around 3 kV/mm, but to make the ions (that create the electrostatic field of the atmosphere) absorb the RF electric field energy giving to them kinetic energy.

The simplest reactor model has two parallel metal plates insulated and separated by an appropriate distance filled with a gas or air. If one electric charge moves across the discharge width from one plate to the other during one full cycle of the RF field, then the RMS (root mean square) displacement of the particle has to be less than half the clear spacing in order to have a build-up of charge between the plates.[3]

The generation of an atmospheric plasma by capacitively coupled RF voltage consumes energy proportional to the volume of air. In our theoretical Lorentzian model of unmagnetized plasma we will consider that the electric voltage applied to the reactor is sinusoidal, applied only to the X axis of our system of rectangular coordinates, therefore:

$$E = E_{x,y,z} = (E_0 \text{sen}(\omega t), 0, 0) \quad \text{and} \quad B = B_{x,y,z} = (0, 0, 0) .$$

The electric power absorbed from the electromagnetic field by an electron is given by:

$$P = \frac{dU}{dt} = e E \frac{dx}{dt} = e E_0 \text{sen}(\omega t) \frac{dx}{dt} .$$

With:

P = Power absorbed by electron [W];

U = Work or energy [J];
 E = Electric field applied on plasma[V m⁻¹];
 E_0 = Electric field peak value applied on plasma[V m⁻¹];
 e = Electric charge of electron = $1.602 \cdot 10^{-19}$ C;
 $\omega = 2\pi f$ = Angular frequency of the RF electric field [rad s⁻¹];
 t = One cycle time [s].

By integrating the power value over a period of oscillation, we will have the total average power absorbed from the electric field of RF by a single electron:

$$\bar{P} = \frac{(e E_0)^2}{2 m_e} \frac{f_c}{\omega^2 + f_c^2} .$$

With:

\bar{P} = Average power absorbed by electron [W];
 m_e = Mass of electron = $9.109 \cdot 10^{-31}$ kg;
 f_c = Collision frequency of electrons and ions in the plasma reactor [Hz].

Since the plasma is in the individual particle regime, we can establish the relation of the average power consumed by m³ of plasma with the product of the power consumed by electron with the electron density of the plasma:

$$\bar{P}_{RF} = n_e \bar{P} = n_e \frac{(e E_0)^2}{2 m} \frac{f_c}{\omega^2 + f_c^2} .$$

With:

\bar{P}_{RF} = Average power density absorbed by the plasma [W m⁻³];
 \bar{P} = Average power absorbed by electron [W];
 n_e = Electron density of the plasma [electrons m⁻³].

The electric energy density of the RF electric field is determined by:

$$u = \frac{1}{2} \epsilon_0 E^2 = \frac{1}{2} \epsilon_0 E_0^2 \text{sen}^2(\omega t) .$$

With:

u = Energy density [J m⁻³];
 ϵ_0 = Permittivity of free space = $8.854 \cdot 10^{-12}$ F m⁻¹;
 E = Electric field applied on plasma[V m⁻¹];
 E_0 = Electric field peak value applied on plasma[V m⁻¹];
 $\omega = 2\pi f$ = Angular frequency of the RF electric field [rad s⁻¹];
 t = One cycle time of the RF field [s].

Integrating the value of the electrical energy density over a period of oscillation, we will have the average energy density absorbed by the plasma:

$$\bar{u}_{RF} = \frac{1}{4} \epsilon_0 E_0^2 .$$

The frequencies used in the RF field can vary from a few kHz to hundreds of MHz. The equation of the electric power density, considering that the frequency of the RF electric field is much lower than the electron collision frequency ($\omega \ll f_c$), may be simplified to:

$$\bar{P}_{RF} = n_e \bar{P} = n_e \frac{(e E_0)^2}{2 m f_c} .$$

This is the electric power density absorbed by a controlled 1 atm plasma produced by a sinusoidal electric field. In this condition, the electric charge density tends to be higher than a lower pressure plasma, which has a lower density of ions to be excited.

To create a pressure differential between the inside and outside of the chamber, it is necessary to spend a greater power than that required to produce a plasma, because in 1 atm industrial plasma the intention is not to lower the pressure, but to establish an ionized region that presents the corona effect.

5 Ions Inside Electrostatic Fields

When the air is ionized inside a chamber, the produced ions are withdrawn and absorbed by the electrostatic field of the surrounding atmosphere and a turbulent region is created in the site, in which the neutral air is partially ionized. The force exerted by the electrostatic field gives kinetic energy to the ions and therefore carries out a work that can be lower or higher than the energy spent in the air ionization process. In this chapter we will calculate this energy.

5.1 Electric Field Force on Ions

When an ion is within an electric field, it is subjected to an attraction/repulsion force equivalent to:

$$\vec{F} = q \vec{E} .$$

With:

F = Electric force [N];

q = Ion electric charge [C];

E = Electric field [V m⁻¹].

Considering that the electrostatic field in the atmosphere is 80 V/m at sea level and that the electron has a charge $e = 1.602 \cdot 10^{-19}$ Coulombs, the force exerted by this electric field on each electron is:

$$\vec{F} = e \vec{E} = 1.602 \cdot 10^{-19} * 80 = 1.2816 \cdot 10^{-17} N .$$

At 10 km of altitude, the force exerted by the atmospheric electrostatic field of 300 V/m on each electron is:

$$\vec{F} = e \vec{E} = 1.602 \cdot 10^{-19} * 300 = 4.806 \cdot 10^{-17} N .$$

5.2 Acceleration of Ions Within Electric Field

Once the ions are produced inside the ionization chamber, as they are immersed in the electrostatic field of the atmosphere, they are displaced by the force calculated above. The electron, which has mass $m_e = 9.109 \cdot 10^{-31}$ kg, at sea level will be subjected to an acceleration of:

$$a = \frac{F}{m_e} = \frac{q E}{m_e} = \frac{1.602 \cdot 10^{-19} * 80}{9.109 \cdot 10^{-31}} = 1.407 \cdot 10^{13} m s^{-2} .$$

At an altitude of 10 km, the electrons will be subjected to an acceleration of:

$$a = \frac{F}{m_e} = \frac{qE}{m_e} = \frac{1.602 * 10^{-19} * 300}{9.109 * 10^{-31}} = 5.276 * 10^{13} \text{ m s}^{-2} .$$

In this condition, the negative ions produced during the dissociation process of the air will undergo an acceleration capable of pulling them out of the site and taking them to the highest atmospheric layers, where the positive electric potential is always greater. In turn, positive ions will be pulled from the site and brought to earth, where the electric potential is negative, but with a lower acceleration because they are heavier than electrons.

In the region of ion production, a low pressure zone is formed which can be controlled by the amount of ions produced with the dissociation and ionization of the air molecules. If all the air is ionized we will have absolute vacuum, if only part of it is ionized we will have partial vacuum.

5.3 Average Speed of Accelerated Ions

The average displacement speed of the accelerated ions, which is the drag speed, is the average of the vector velocity of the ions that are under the action of an electric field. The acceleration provided by the electric field does not lead to a uniformly accelerated motion because of collisions. The accelerated motion of an ion only lasts between one collision and another. After a collision, the ion acquires an arbitrary velocity and loses the result of the acceleration it had suffered before it. The result of the acceleration of the electric field over all ions is a finite drag velocity constant in time, which can be expressed as a function of the relaxation time τ , which is a measure of the effective duration of accelerated motion.

In the atmosphere, the relaxation time is the inverse of the collision frequency of electrons and ions in the air, which varies as a function of atmospheric pressure and temperature. Using this relation $\tau = 1/f_c$, for an electric field E acting on a particle of charge q and mass m , the equation of the mean displacement speed is:

$$v_d = a \tau = \frac{a}{f_c} = \frac{F}{m f_c} = \frac{qE}{m f_c} .$$

With:

- v_d = Average displacement speed [m s^{-1}];
- a = Acceleration of ion [m s^{-2}];
- $\tau = 1/f_c$ = Time between collisions (relaxation time) [s];
- f_c = Collision frequency [Hz];
- F = Electric force [N];
- m = Mass of the ion [kg];
- q = Electric charge of ion [C];
- E = Electric field [V m^{-1}].

The query to the collision frequency table presented in [Electrostatic Field of the Atmosphere](#) gives us at sea level and at 300K a frequency $f_c = 4.66 * 10^{11}$ collisions/s, corresponding to a time $\tau = 2.146 * 10^{-12}$ s/collision; at 10 km altitude and at 300K, $f_c = 2.36 * 10^{10}$ collisions/s, which corresponds to a time $\tau = 4.237 * 10^{-11}$ s/collision.

At sea level, electrons have the lowest mean displacement speed:

$$v_d = \frac{eE}{m_e f_c} = \frac{1.602 * 10^{-19} * 80}{9.109 * 10^{-31} * 4.66 * 10^{11}} = 30.2 \text{ m s}^{-1} .$$

At higher altitudes there is higher electrostatic field and lower collision frequency, so the mean speed of the accelerated ions is higher. At 10 km altitude electrons have an average speed of:

$$v_d = \frac{e E}{m_e f_c} = \frac{1.602 * 10^{-19} * 300}{9.109 * 10^{-31} * 2.36 * 10^{10}} = 2.24 * 10^3 \text{ m s}^{-1} .$$

5.4 Electrostatic Field Work on Ions

When an electric field exerts a force on an electric charge or ion during a time, it does a work on the charge equivalent to $W = F d = q E d$. In the stable condition of the air ionization process, the mean displacement speed v_d is considered constant and the displacement time τ is the duration between two collisions, hence the distance between collisions and the work done by the electric field on the charge are:

$$d_c = v_d \tau = \frac{v_d}{f_c} = \frac{q E}{m f_c^2} \quad \text{and} \quad W_q = F d_c = q E \frac{v_d}{f_c} = \frac{(q E)^2}{m f_c^2} .$$

This is the energy expended by the electrostatic field accumulated in the atmosphere to move an ion until the first collision. After this first collision, the ion will be accelerated again until the next collision, when a new amount of energy is expended. This situation will continue until the ion is displaced from the ionization chamber and placed in the atmosphere, subjected to the balance between charge, electric field and other forces.

At sea level, the distance between collisions and the work done by the atmospheric electrostatic field to displace an electron (negative ion) to its first collision are:

$$d_c = \frac{e E}{m_e f_c^2} = \frac{1.602 * 10^{-19} * 80}{9.109 * 10^{-31} * (4.66 * 10^{11})^2} = 6.48 * 10^{-11} \text{ m} ,$$

$$W_e = \frac{(e E)^2}{m_e f_c^2} = \frac{(1.602 * 10^{-19} * 80)^2}{9.109 * 10^{-31} * (4.66 * 10^{11})^2} = 8.30 * 10^{-28} \text{ J} .$$

At 10 km altitude, the distance between collisions and the work done by the atmospheric electrostatic field to displace an electron (negative ion) to its first collision are:

$$d_c = \frac{e E}{m_e f_c^2} = \frac{1.602 * 10^{-19} * 300}{9.109 * 10^{-31} * (2.36 * 10^{10})^2} = 9.47 * 10^{-8} \text{ m} ,$$

$$W_e = \frac{(e E)^2}{m_e f_c^2} = \frac{(1.602 * 10^{-19} * 300)^2}{9.109 * 10^{-31} * (2.36 * 10^{10})^2} = 4.55 * 10^{-24} \text{ J} .$$

However, our interest is the energy expended to remove an ion from within the plasma production region, so the distance is not measured between two collisions, but between the position of the ion and the periphery of the ionization chamber. Besides that, the number of charges produced in the ionization chamber is proportional to the differential pressure between the inside and outside of it, $n_e = n_0 \Delta P$. In an ionization device with density of electrons n_e , the work per m^3 carried out by the electric field will be:

$$u = n_e \frac{W_e}{d_c} = n_e e E d = n_0 \Delta P_{[atm]} e E d [J \text{ m}^{-3}] .$$

To calculate the energy per m³ spent by the electric field of the atmosphere to remove these ions from the ionization chamber and realize useful work, we must estimate the distance traveled by the electrons as they are pulled by the electric field of the atmosphere.

In the case of an RF ionization chamber, where the ionization zone is limited by a metal plate and screen separated by an electric isolating wall, the distance will be half the thickness of the chamber (the distance between the plate and the screen), which will determine the average energy. Our estimate for the thickness of the ionization chamber to be tested is 24 mm, so the average path of the electrons inside the chamber will be $d = 12$ mm.

Knowing that the molecular density of atmosphere is related with the atmospheric pressure by $n_0 = 2.415 * 10^{20} P_{[N/m^2]}$ and consulting the altitude x pressure table in [Electrostatic Field of the Atmosphere](#), we can calculate the density of gas molecules per m³ at any altitude. At sea level, the electrostatic field of the atmosphere is about 80 V/m and we have a density of gas molecules of $2.447 * 10^{25}$ molecules/m³. Considering the ionization of these molecules to create a differential pressure ΔP , the energy (work done) per m³ will be:

$$u = n_0 \Delta P_{[atm]} e E d = 2.447 * 10^{25} * \Delta P_{[atm]} e * 80 * d = 3.763 * 10^6 * \Delta P_{[atm]} [J m^{-3}] .$$

At 10 km altitude, the electrostatic field of the atmosphere is about 300 V/m, and for a density of gas molecules of $6.440 * 10^{24}$ molecules/m³, the energy per m³ spent by the electric field of the atmosphere will be:

$$u = n_0 \Delta P_{[atm]} e E d = 6.440 * 10^{24} * \Delta P_{[atm]} e * 300 * d = 3.714 * 10^6 * \Delta P_{[atm]} [J m^{-3}] .$$

As we may see, the energy is almost the same at sea level and at 10 km altitude. However, the atmospheric electric field performs a larger work because it displaces the negative ions to the high layers and the positive ions to the low layers of the atmosphere. Besides that, these charges ionize the neutral air molecules during their trajectory as they leave the chamber, therefore we will have an additional work.

For our first approximation, we will consider that the work done in the first 50 cm of ion's course will be useful, so the mean energy per m³ spent by the electrostatic field of the atmosphere at sea level, and approximately for any altitude, considering $d = 50$ cm, will be:

$$u = 2.447 * 10^{25} * \Delta P_{[atm]} e E d = 1.568 * 10^8 * \Delta P_{[atm]} [J m^{-3}] .$$

This is the volumetric density of energy spent by the atmosphere to remove the ions from the interior of the ionization chamber and create a pressure difference of $\Delta P_{[atm]}$ between the inside and outside of the chamber, considering that the useful work is done in the first 50 cm of the ions trajectory. This is the available raw energy with this system.

5.5 Electrostatic Field Power on Ions

The power spent by the atmospheric electrostatic field to displace an electric charge from the ionization chamber with an average displacement speed is:[3]

$$P_q = W_q f_c = F d_c f_c = q E v_d = \frac{(q E)^2}{m f_c} .$$

With:

P_q = Power per ion [W];

W_q = Energy or Work done by the electric field on ion [J];

f_c = Collision frequency [Hz];

F = Force of the electric field on the charge [N];
 d_c = Distance between collisions [m];
 q = Electric charge of ion [C];
 E = Electric field [$V\ m^{-1}$];
 v_d = Average displacement speed [$m\ s^{-1}$];
 m = Mass of the ion [kg].

We have found the same equation of the power spent by the RF electric field in ionizing the air between two metallic plates equated in the [Atmospheric Plasma](#) chapter. The only difference is that the electrostatic field of the atmosphere is not sinusoidal, so the mean power has not the factor $\frac{1}{2}$.

At sea level, with atmospheric electrostatic field $E = 80\ V/m$ and collision frequency $f_c = 4.66 \cdot 10^{11}\ Hz$, the power spent per electron is:

$$P_e = \frac{(eE)^2}{mf_c} = \frac{(1.602 \cdot 10^{-19} \cdot 80)^2}{9.109 \cdot 10^{-31} \cdot 4.66 \cdot 10^{11}} = 3.87 \cdot 10^{-16}\ W \quad .$$

With $n_e = 2.447 \cdot 10^{25} \cdot \Delta P_{[atm]}$ electrons/ m^3 , the power per m^3 is:

$$P_{m^3} = n_e P_e = n_e \frac{(eE)^2}{mf_c} = 2.447 \cdot 10^{25} \Delta P_{[atm]} \frac{(1.602 \cdot 10^{-19} \cdot 80)^2}{9.109 \cdot 10^{-31} \cdot 4.66 \cdot 10^{11}} = 9.47 \cdot 10^9 \Delta P_{[atm]} [W\ m^{-3}] \quad .$$

At 10 km altitude, with atmospheric electrostatic field $E = 300\ V/m$ and collision frequency $f_c = 2.36 \cdot 10^{10}\ Hz$, the power spent per electron is:

$$P_e = \frac{(eE)^2}{mf_c} = \frac{(1.602 \cdot 10^{-19} \cdot 300)^2}{9.109 \cdot 10^{-31} \cdot 2.36 \cdot 10^{10}} = 1.07 \cdot 10^{-13}\ W \quad .$$

With $n_e = 6.440 \cdot 10^{24} \cdot \Delta P_{[atm]}$ electrons/ m^3 , the power per m^3 is:

$$P_{m^3} = n_e P_e = n_e \frac{(eE)^2}{mf_c} = 6.440 \cdot 10^{24} \Delta P_{[atm]} \frac{(1.602 \cdot 10^{-19} \cdot 300)^2}{9.109 \cdot 10^{-31} \cdot 2.36 \cdot 10^{10}} = 6.92 \cdot 10^{11} \Delta P_{[atm]} [W\ m^{-3}] \quad .$$

These are the volumetric density of power spent by the atmosphere to remove the ions from the interior of the ionization chamber and create a pressure difference of $\Delta P_{[atm]}$ between the inside and outside of it at sea level and 10 km altitude. These are the available raw power with this system.

6 Energy and Power Gain of this System

There are two gains to consider, energy and power. The energy gain depends on the distance traveled by the ions in its withdrawn from the ionization chamber that produces useful work (here estimated in 50 cm). The power gain is not associated with a specific trajectory, it merely indicates the power required to maintain the amount of $2.447 \cdot 10^{25}$ ions/ m^3 at a specific displacement speed.

1. Energy gain:

In this calculation, we compare the energy spent by a RF generator to ionize 1 m^3 of atmospheric air at sea level ($6.117 \cdot 10^7\ J/m^3$), as we calculated in the [Ionization Energy of Atmospheric Air](#) chapter, with the energy spent by the electrostatic field of the atmosphere

when moving 1 m³ of ionized air at sea level (1.568*10⁸ J/m³), considering that the useful work is done in the first 50 cm of the ions trajectory, as we calculated in the [Electrostatic Field Work on Ions](#) chapter. We can thus estimate the gain in energy of this system at any altitude through the equation:

$$Gain = \frac{W_{atm}}{W_{RF}} = \frac{1.568 * 10^8}{6.117 * 10^7} \approx 2.6 \quad .$$

The limit for the useful working distance of the ions trajectory, where Gain = 1, is 20.15 cm; if the distance is smaller, then there will be no gain, so there is a scale factor that could impact the general energy gain.

2. Power gain:

In this calculation, we compare the power spent by a RF generator to ionize 1 m³ of atmospheric air at sea level (6.318*10⁷ W/m³), as we calculated in the [Ionization Power of Atmospheric Air](#) chapter, with the power spent by the electrostatic field of the atmosphere when moving 1 m³ of ionized air at sea level (9.468*10⁹ W/m³), considering that the ions are withdrawn from the ionization chamber with a specific displacement speed, as we calculated in the [Electrostatic Field Power on Ions](#) chapter. We can thus estimate the gain in power of this system at sea level through the equation:

$$Gain = \frac{P_{atm}}{P_{RF}} = \frac{9.47 * 10^9}{6.117 * 10^7} \approx 155 \quad .$$

The power gain increases with altitude, so this is the minimum power gain. At an altitude of 10 km the power gain is estimated in:

$$Gain = \frac{P_{atm}}{P_{RF}} = \frac{6.92 * 10^{11}}{6.117 * 10^7} \approx 1.13 * 10^4 \quad .$$

7 Ionization Chamber Applications

Taking into account the calculations made above, it is convenient to present some construction directives for ionization chambers that produce differential atmospheric pressure using high-voltage RF generators. These generators are largely used in the inductive heating industry, taking care of recalculating the primary coil and adding a calculated resonant high-voltage secondary coil, or using high-voltage resonant Tesla generators, or any other fixed or variable medium frequency non-resonant high-voltage electric generators. Here, it will not be discussed the high voltage system, but a prototype chamber for testing purposes.

It is not easy to dimension a new device without already tested parameters, so these directives are only suggestions and may vary greatly with the RF frequency used, continuous or pulsed RF field, the amplitude of the delivered secondary high-voltage, the thickness of the ionized air layer, air humidity etc. They are parameters that affect the “scale factors” that are out of control for the calculations made here, so take into account the need to change any parameters.

7.1 Ionization Chamber

The ionization chamber must be projected so that it is pushed by the atmospheric pressure that stay on the opposite side of the low pressure side of a board. This way, it may consist of a metallic conducting board, a perforated electric insulating separator, a metallic conducting wire grid

and a perforated insulating cover. The wire grid remains separated from the plate by the separator thickness distance, that maintains the insulation between the parts, prevents the lateral entry of the air and fixes the wire grid with a recess. The separator and cover must have an area only sufficient to mechanically secure the assembly, remaining unobstructed the largest possible area of the grid and the plate, to allow the largest area for air entry. The assembly is fixed by screws that pass through the insulators and the plate. The following figures show the parts that makes a hypothetical ionization chamber.

The board, separator and cover have six holes with a 60° angular separation for fixing the parts with six screws, pressure washers and nuts. Two or more of these screws may have longer length for chamber attachment.

The metallic board must conduct electricity, so it can be made of aluminum, stainless steel, brass or any rigid metal that, when attached to a chassis or cradle, withstands the traction force of the chamber.

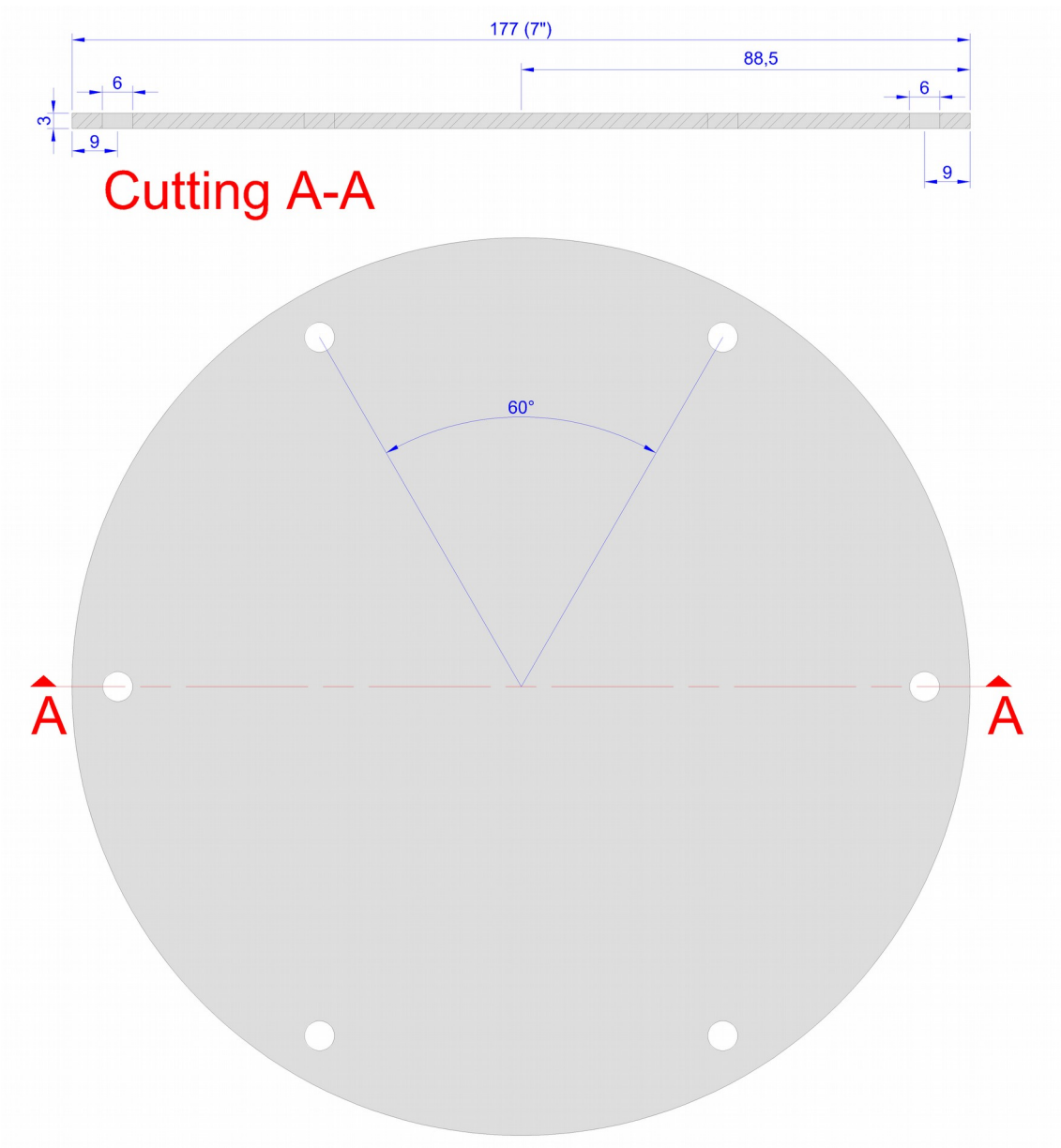


Figure 3: Metallic conducting board.

The separator and the cover can be made of celeron, PTFE, nylon or any electric insulating material with a thickness calculated to withstand the high-voltage without breaking the insulation. It is convenient to predict a temperature increase in the metallic parts resulting from the collision of ions; if this happens to a high degree, perhaps these parts must be done of porcelain or ceramics.

The separator has a recess for grid fitting that allows its electrical contact strip to come out of the chamber.

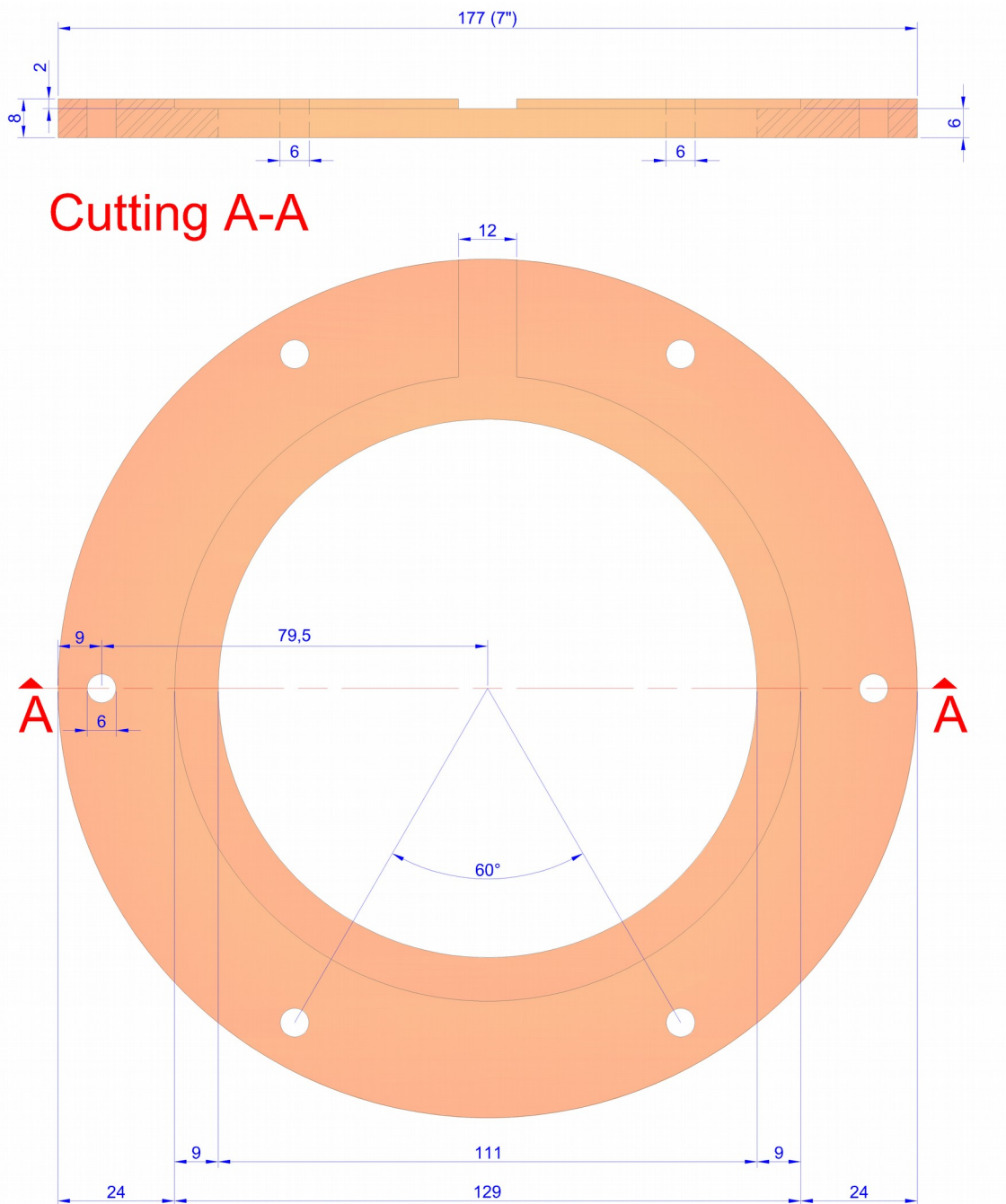


Figure 4: Hollow insulating separator.

The metallic wire grid must conduct electricity and allows the air entrance, so it can be made of approximately 0.5 mm in diameter with a 1 mm wire spacing. These measures vary according to the area of the chamber. Because of the inevitable ion collisions, the temperature of this grid should increase a lot, so it is advisable to use stainless steel wire. It is convenient to weld a frame around the grid to fix its wires and maintain a rigid surface to withstand the pressure of the air intake. This frame must have a soldered strip to allow its electrical connection to the high-voltage pole.

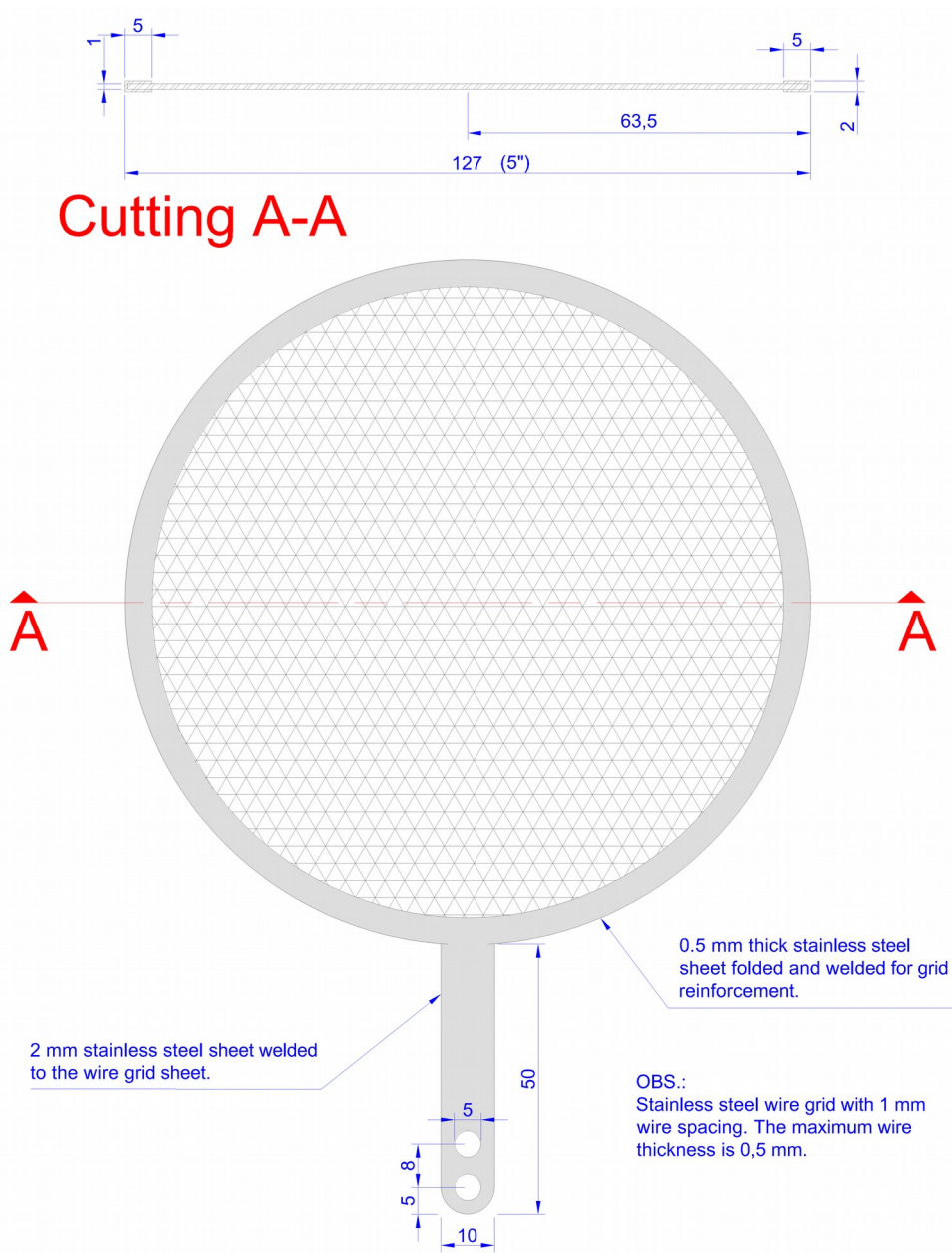


Figure 5: Metallic conducting wire grid.

The cover serves to fix the grid in the recess of the separator and its electrical insulating material provides the upper electrical insulation for the metal grid, so that the high-voltage is confined within the chamber.

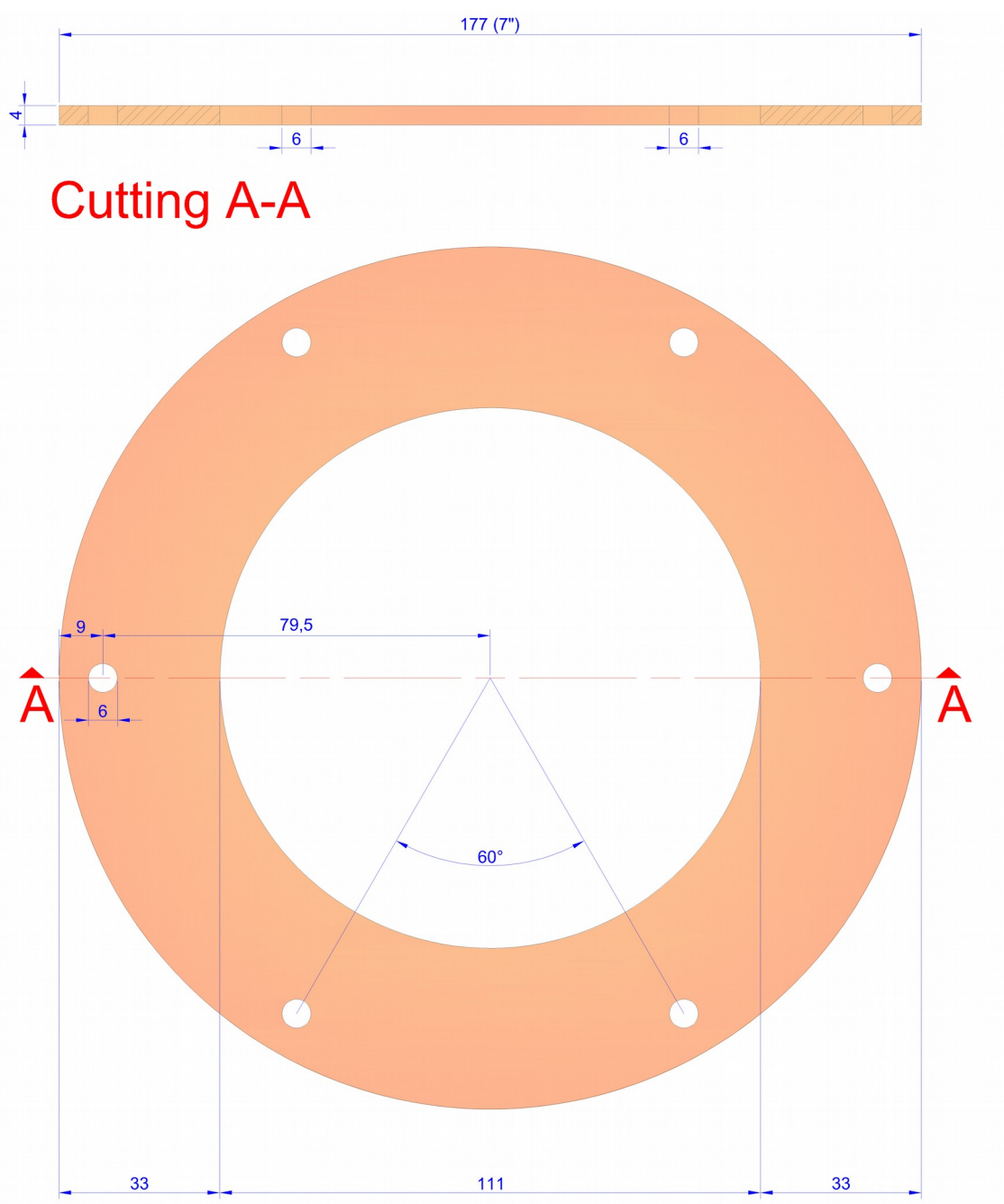


Figure 6: Hollow insulating cover.

Assembly is done by placing the separator on the metallic board, the metallic wire grid on the recess of the separator, the cover on the separator with the metallic wire grid, and the whole assembly is fixed with six screws, lock washer and nuts.

The thickness of the separator affects the high-voltage used in this device. If the distance between the grid and the board is 3 mm, the required high-voltage will not be as high as if the distance is 6 mm, unless the frequency is higher. Perhaps it is necessary to put several insulators and grids mounted one over the other to reach the required low pressure inside the chamber. If this is the case, the high-voltage may be applied in intercalated grids, without connecting the high-voltage to the board, that may be connected to the ground system for safety reasons.

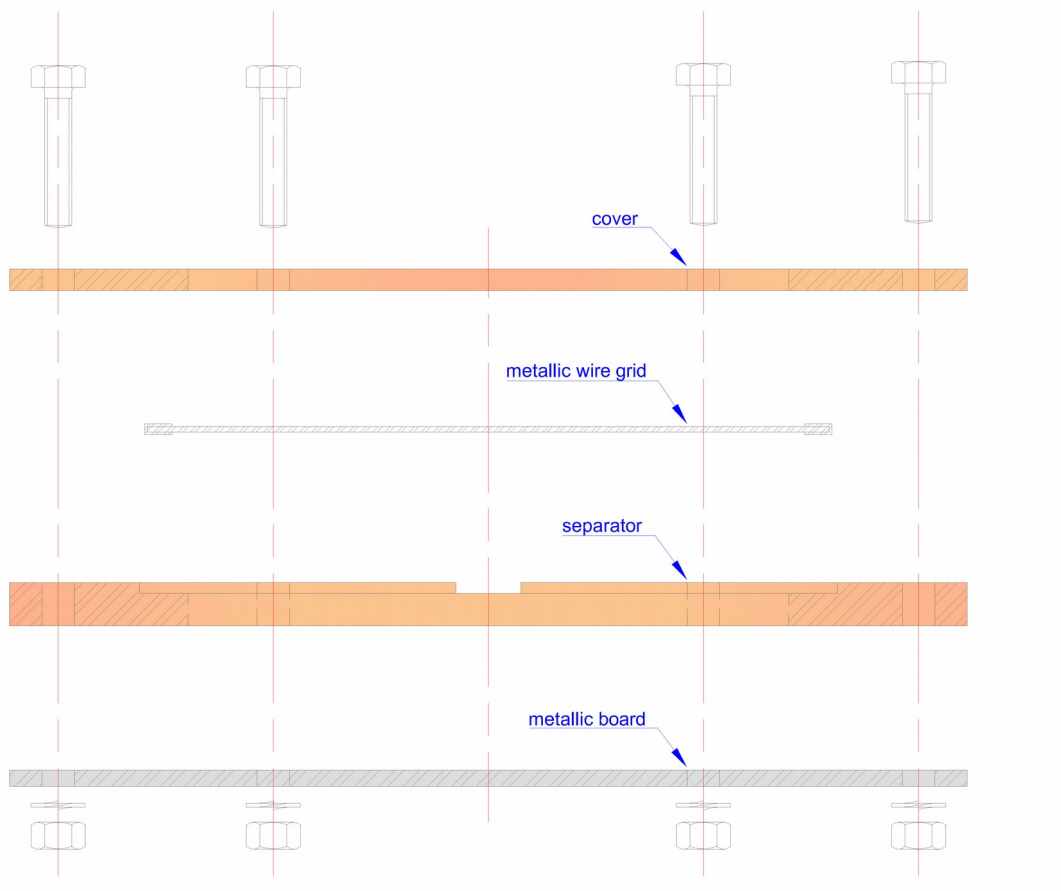


Figure 7: Assembly cutting of the ionization chamber's parts.

One secondary pole of the RF generator is connected to the metallic board and the other to the metallic wire grid, so the air between the plate and the grid is ionized. Thus, the grid allows the output of ions and the entrance of air to ionize. The ionization of the air produces a low pressure inside the chamber, but since the opposite side of the board is at normal pressure, a pressure difference is created between its two faces, which can be used to turn a rotor, move the shovels of a turbine or push/pull a vehicle.

To calculate the resulting force due to the pressure difference on both sides of the plate and the necessary chamber surface to ionize, we have:

$$F = \Delta P * S = (P_a - P_i) S \implies S = \frac{F}{P_a - P_i} .$$

With:

- F = Force [N];
- ΔP = Pressure difference [$N\ m^{-2}$];
- S = Ionization area [m^2];
- P_a = Atmospheric pressure [$N\ m^{-2}$];
- P_i = Pressure inside chamber [$N\ m^{-2}$].

As an example, let's use the dimensions of the proposed ionization chamber of the figures, that has ionization surface of $95\ cm^2$ and consider a pressure of $\frac{1}{2}$ atmosphere inside the chamber. The resulting force will be:

$$F = (P_a - P_i) S = (1.013 * 10^5 - 5.065 * 10^4) 9.503 * 10^{-3} = 481.3\ N .$$

With:

$$\begin{aligned} P_a &= 1 \text{ atm} = 1.013 \cdot 10^5 \text{ N m}^{-2}; \\ P_i &= \frac{1}{2} \text{ atm} = 5.065 \cdot 10^4 \text{ N m}^{-2}; \\ S &= \pi r^2 = \pi (5.5 \cdot 10^{-2})^2 = 9.503 \cdot 10^{-3} \text{ m}^2. \end{aligned}$$

If the chamber is positioned with the wire grid facing up, this resulting force will be pointing from bottom up and will neutralize the gravity force of a mass:

$$m = \frac{F}{g} = \frac{481.3}{9.807} = 49.08 \text{ kg} .$$

If the weight of the chamber is 3 kg, the vertical acceleration will be:

$$a = \frac{\Delta F}{m} = \frac{F - mg}{m} = \frac{481.3 - 3 \cdot 9.807}{3} = 150.6 \text{ m s}^{-2} .$$

7.2 Propulsion System

To use the ionization chamber for vehicle traction, it suffice to put a unit with the metallic board rigidly attached on the chassis, in place of the vehicle combustion engine. The chamber may have two wire grids mounted on both sides of the board to permit front or rear wheel drive, ionizing the front or back grid respectively.

Let's estimate the required area of an ionization chamber to propel a 1,500 kg vehicle from 0 to 100 km/h in 5 seconds, considering that the pressure inside the chamber is $\frac{1}{2}$ atmosphere. The needed acceleration is:

$$a = \frac{v_f - v_i}{t} = \frac{27.78 - 0}{5} = 5.556 \text{ m s}^{-2} .$$

With:

$$\begin{aligned} a &= \text{Acceleration [m s}^{-2}\text{]}; \\ v_f &= \text{Final speed} = 100 \text{ km/h} = 27.78 \text{ m s}^{-1}; \\ v_i &= \text{Initial speed} = 0 \text{ km/h}; \\ t &= \text{Time} = 5 \text{ s}. \end{aligned}$$

The needed force to get this acceleration is:

$$F = m a = 1,500 \cdot 5.556 = 8,334 \text{ N} .$$

With:

$$\begin{aligned} F &= \text{Force of traction [N]}; \\ m &= \text{Mass of vehicle} = 1,500 \text{ kg}. \end{aligned}$$

The needed area of the ionization chamber is:

$$S = \frac{F}{P_a - P_i} = \frac{8.334 \cdot 10^3}{1.013 \cdot 10^5 - 5.065 \cdot 10^4} = 0.1644 \text{ m}^2 .$$

With:

$$\begin{aligned} S &= \text{Area of the ionization chamber [m}^2\text{]}; \\ P_a &= 1 \text{ atm} = 1.013 \cdot 10^5 \text{ N m}^{-2}; \\ P_i &= \frac{1}{2} \text{ atm} = 5.065 \cdot 10^4 \text{ N m}^{-2}. \end{aligned}$$

This area can be implemented by a chamber with 20 cm x 80 cm ionization area.

8 Conclusion

The electrostatic field stored in the planet's atmosphere ranges from 80 V/m to 300 V/m. This field withdraw ions produced inside an atmospheric air ionization chamber and produces a low pressure zone inside it. Because the atmospheric pressure is all around any object inside the atmosphere, the differential pressure between inside and outside of the chamber produces mechanical work which can be harnessed as trust force.

The necessary volumetric density of energy spent to create a differential atmospheric air pressure ΔP at sea level is:

$$u = 6.117 * 10^7 * \Delta P_{[atm]} [J m^{-3}] \quad .$$

The power required to maintain a differential pressure ΔP is proportional to the speed of air entering the chamber and the air intake area. The result of these considerations is the volumetric density of power at sea level:

$$P_{m3} = 6.117 * 10^7 * \Delta P_{[atm]} [W m^{-3}] \quad .$$

The volumetric energy spent by the electrostatic field of the atmosphere to extract electric charges from the chamber takes into account the distance traveled by these charges that relates to useful work. If we consider a useful distance of 50 cm, the volumetric energy at a differential pressure of ΔP at sea level is:

$$u = 1.568 * 10^8 * \Delta P_{[atm]} [J m^{-3}] \quad .$$

The power spent by the electrostatic field of the atmosphere do not consider the distance, but the displacement speed of the charges. At sea level, the volumetric power is:

$$P_{m3} = 9.47 * 10^9 * \Delta P_{[atm]} [W m^{-3}] \quad .$$

According to the values of electrical energy and power required to ionize a volume of atmospheric air and energy and power spent by the electrostatic field of the atmosphere to absorb these ions, it is possible that this electrostatic field produces more energy than that which was spent to ionize the air. The energy gain was evaluated as 2.6; the power gain at sea level was 155 and at elevated altitudes the gain is larger. This signifies that mounting such systems in mountainous regions there will be substantial gains. These are promising values that deserve better investigation, experimentation and tests.

Besides that, it can be an alternative propulsion system with many advantages over the current transport systems because it is not polluting and there is much simplicity in its implementation. For example, in a car there must be an RF high-voltage generator, that is a sophisticated version of the actual ignition car coil, and a metallic board with two metallic grids on its opposite sides separated by an insulating material. The high voltage is connected between the board and the grids. To go forward, the high-voltage is connected in the front grid, to go back, it is connected in the back grid. This ionization chamber replaces the combustion engine.

On the other hand, if the gain of this system is experimentally proven, it is possible to replace our power plants (nuclear, charcoal, fossil fuel, geothermic, hydroelectric etc.) with those based on atmospheric pressure difference created by atmospheric ionization chambers, with the advantage of portability and without the need for reservoirs or sources of combustible materials.

This ionization chamber technology has limitations for larger areas because the power needed for the RF generators would be very high, but microwaves and cathodic rays are promising technologies for electric power plants and large mechanical propulsion systems.

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