Space Science in Thermodynamics

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Abstract
There are various strategies to make physics more appealing for pupils. I believe the significantly increased involvement of the results of space research could be a possible way. The success story of ESA CubeSats and Education – Fly Your Satellite! Programme offers excellent opportunity for an increased exposure of space research, as those university students who designed and created these satellites are slightly older than our secondary school pupils. By satellites, interest towards a technical vocation could be raised among the secondary school age group. In my presentation I demonstrate that nearly all topics of thermodynamics support an outlook to space as well, without neglecting the experiments and examples used for decades. When teaching the concept of thermodynamics we can talk about the temperature of Earth's atmosphere and the temperature of space, about the warming and cooling of satellites. At heat transfer methods we can analyse the radiations affecting the satellites. Taking off from the surface of Earth, we can wander into the topic of greenhouse effect. In solving problems in the topic of thermal expansion, we can again use satellites. When teaching the change of physical state, arctic see ice extent may be mentioned and in relation to this we can speak about the role satellites play in the research of climate change. Moving into space, we can talk about space weather that affects the operation of satellites. In relation to the principles of thermodynamics, the relatively new concept of space debris can also be explored. In my experience, pupils in physics classes sometimes love to leave Earth and wander in space in their imagination. Compared to previous years, relatively more pupils of mine, who are interested in music art, choose physics for final exams, even on advanced level, and take part in competitions.

Keywords
Thermodynamics, space research, satellite, cubesat

Introduction

The teaching of physics has been in a difficult state for the last decades not only in Hungary but in all of Europe. Most students do not like physics, and our task as teachers is to change this. There are many teachers who try to do something – depending on the availability of resources at their schools – so that physics can become more appealing to students. It is important that due to these efforts, not only will more students want to join physics faculties at universities or choose careers in engineering, but all students will enjoy this subject. I teach at a secondary school which doubles as a music conservatory, and cope with overcoming this challenge regularly.
I want to begin by saying that in the twenty-first century – a time when the media often talks about issues influencing the future of humanity – it is essential that we no longer use only the same examples we did two decades ago when we taught the basic notions and laws of physics.

We have to keep up with the latest scientific research, because its results are very interesting and allow the students to better understand the curriculum. It is necessary to discuss not only the results of such research, but to explain how they are used in real life. This way, there will be no “gap” between students’ knowledge of the main curriculum and their knowledge of the phenomena of everyday life. In this article I want to illustrate how one can use the results of space research in the teaching of thermodynamics.

At first it may seem like a risky venture to say that we can illustrate and explain the basic laws of large, separate areas of physics in secondary school with, for instance, satellites and space probes. But if we look more closely, we can see that, surprisingly, there is a wide range of possibilities in this area. I have been focusing on this topic for some years now, and have continuously tried to increase the application of space exploration in my physics teaching. I chose space research because in our everyday lives we encounter tools and services related to it almost every minute. These rely on cutting-edge technology and represent the successes of serious research, quite often space research. In addition, through space exploration we also expand our knowledge of astronomical phenomena, which have a determinate role in the destiny of our planet. In spite of this, so far the topic of space research is touched upon only in 2-3 lessons in the physics curriculum in Hungary, and has only now been given a little more importance.

I usually attempt to make lots of references to the MaSat-1 Hungarian picosatellite, which was made for educational purposes, and is part of the CubeSat program of ESA. The MaSat-1 has functioned perfectly for almost 3 years as opposed to the predicted 3 months. It is also important to note that the planners of MaSat-1 were mostly university students, who were barely older than secondary school students (http://cubesat.bme.hu/en/). This fact may help bring the subject of physics closer to students. Experiments are very important in the teaching of physics, and MaSat-1 happens to be a great experiment.

Temperatures on Earth and in space

In class, we can work with a web page that tracks satellites (e.g. http://www.n2yo.com/) and ask the students to figure out the temperature zone in which the tracked satellite is orbiting at the moment. We then explain to the students that satellites must be functional in a very large range of temperatures. After that, we can discuss the pronounced temperature differences between the sunny and shadowy sides of an orbiting satellite, which can be very large (hundreds of degrees Kelvin), in spite of the fact that the ambient temperature along the orbit is constant. Satellites are therefore usually are quickly spinning by design in order to avoid mechanical tensions, which could otherwise cause a malfunction. In the case of the aforementioned CubeSat program’s MaSat-1 picosatellite, the satellite’s inner temperature was continuously monitored throughout its lifespan, and when it dropped below 5ºC ground control switched on the heating in order to protect its sensitive accumulator. The internal heating was necessary when the orbiting phase of Masat-1 was located in the shadow of Earth and therefore the solar panels could not utilize the energy of the Sun.

Still maintaining our focus on temperature, we can mention remote sensing satellites again; namely that they can help us in the forecast of volcano eruptions by tracking the temperature above a crater, which rises before an eruption. This temperature increase is detected by the remote sensors of satellites. For the sake of curiosity, we can show the heat map of 67 comets, which was made in August 2014 [1]. It helped scientists find a good landing spot on a comet for Rosetta's landing probe Philae. They chose a site which was neither too hot nor too cold for the Philae Lander.

Heat Transfer and the Greenhouse Effect

After a discussion of the fundamental methods of heat transfer, we can ask: which of these methods do not exist in the space? It is helpful to analyse the heat radiation that reaches a satellite using the following Figure 1.

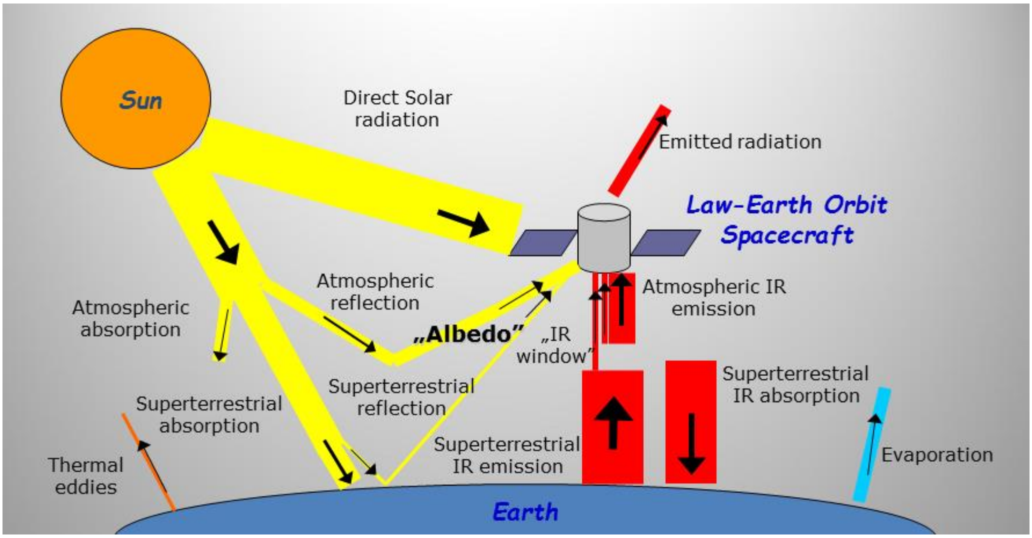

Figure 1. Radiation affecting low-orbiting satellites

On the other hand, it is important to note that the only way by which a satellite can get rid of excess heat is the irradiation of its surface. We should emphasize that this phenomenon was already known by Kirchoff in the nineteenth century. By means of Figure 2, we can discuss the notion of planetary albedo, which is substantially different from surface albedo. We can also teach the basics of greenhouse effect in the figure. The different greenhouse gases absorb the largest part of infrared radiation emitted by the Earth surface, warm up the atmosphere, and re-emit energy toward the Earth and space. We can also mention Venus where the greenhouse effect is the strongest in the Solar System.

It is important to emphasize that CO_2, which is often said to be the most significant factor in greenhouse effect, is responsible only for 10-25% of atmospheric warming, the rest is determined by water vapour (36-72%).

Thermal Expansion and Spacecraft Shields

When teaching this topic – after we do some basic experiments – it is worth to picture ourselves go to space. It is quite didactic to discuss the exercise in which we ask what the percentage of change was in the length of the side of MaSat-1 and in its surface and volume, when the internal temperature reached the critically low temperature of 5°C, compared to what they were at the place of launch, where the temperature was 25°C. At first glance, the task looks simple. We can tell the student that the material of the cube is a special type of aluminium, and one can find the coefficient of thermal expansion in a data booklet. Several students will simply take the value from the table, plug it into the correct formula, and calculate the answer thinking that everything is correct. They will neglect the facts that the thermal coefficient of thermal expansion which was in the table is valid only at the normal atmospheric pressure of 101325 PA, and the cubesat is not made from a homogeneous piece of bulk metal. By means of this example, we can discuss more effectively what a huge challenge it was for the designers of MaSat-1 to choose suitable materials for the shell, fittings, soldering, inner joints of the integrated circuits, etc, which function well in space.

Here we can mention space technology, which deals with the research and developments that allow the operation of a spacecraft. A good example of the achievements of space technology is that the fluctuation of the inner temperature of VesselSat-2 – which is a Luxembourgian micro satellite and CubeSat built and owned by LuxSpace, with an edge of 30cm – is maximum 1 degree centigrade when the satellite moves in orbit, and is at most 6 degrees centigrade due to the change of seasons (source: http://space.skyrocket.de/doc_sdat/vesselsat-1.htm). The role of the spacecraft shield can be an excellent topic to research for the students. We can motivate them with a video from a website dealing with space research, which describes the inflatable spacecraft shield [2], for example.

Gas Laws

While teaching gas laws, we can examine again the Earth's atmosphere. We can review measurements on the density of atmospheric gases decreases with altitude. As an extracurricular activity, we can discuss in more detail that, according to the barometric formula, pressure decreases exponentially with altitude. That formula determines the dependence of the pressure or density of an ideal gas on altitude in a homogeneous gravitational field at a constant temperature. We call to the student's attention that it is better to use the logarithmic scale to graphically visualize the exponential relationship. (See "Pressure" in Figure 2). Analysing parallel the panels in Figure 2 ("Temperature vs. Altitude" and "Pressure vs. Altitude"), we may find a discrepancy about the assumption of constant temperature. But if we investigate it further, we will conclude that the change of absolute temperature remains in a narrow range compared to the change of pressure, however a slight undulation (two barely noticeable bulges) is visible on the pressure profile, as a consequence of changing temperature.

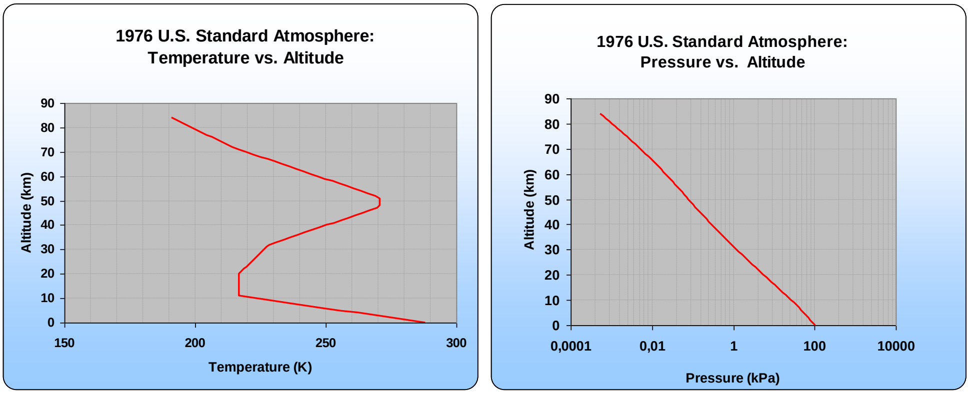

Figure 2. Change of temperature and pressure of atmosphere (Source: http://faculty.virginia.edu/ribando/modules/xls/ accessed Jun 09, 2016)

We can explain to the class that Earth's atmosphere does not have a clear-cut border. Approximately at an altitude of approximately 300-400 km, the density of atmosphere continuously approaches the density of interplanetary space in the solar system. Here we should mention that the orbiting height of satellites must be at least at this altitude in order to ensure their smooth operation. It is beneficial to now take a detour to Mars and Venus. The global chemical composition of these terrestrial planets is very similar to that of Earth, but the most significant component of their atmosphere is CO_2. The atmosphere of Mars is so sparse that the pressure on the surface is only 0.7-0.9 kPa. In contrast to that, the pressure on the surface of Venus is 9.2 MPa. Besides the pressure, the surface temperature on these planets is very different from that of the Earth (218K on Mars and 730K on Venus).

Changing States of Matter and Climate Change

We teach the changing states of a system in the subject of thermodynamics. However, in a 21st century physics class, we should not only talk about the melting of ice in a glass. We should also bring attention to the problem of the shrinking of permanent ice covers, thus arriving at the topic of global climate change. Here, satellites help us again; with them we can follow changes in the ice covers**.** As an example, Figure 3 illustrates annual melt day anomalies (the number of days when ice melt was reported compared to a 30 year average value) in four consecutive years. Climate change cannot be observed and interpreted by means of short sampling periods. The limited accuracy of climate projections is due to missing instrumental records of historical data, and deficiencies in the numerical models. Satellite measurements today provide data of continuous global geographic covering on hundreds of atmospheric and oceanic parameters, however a dense enough network of meteorological satellites operates only for a couple of decades.

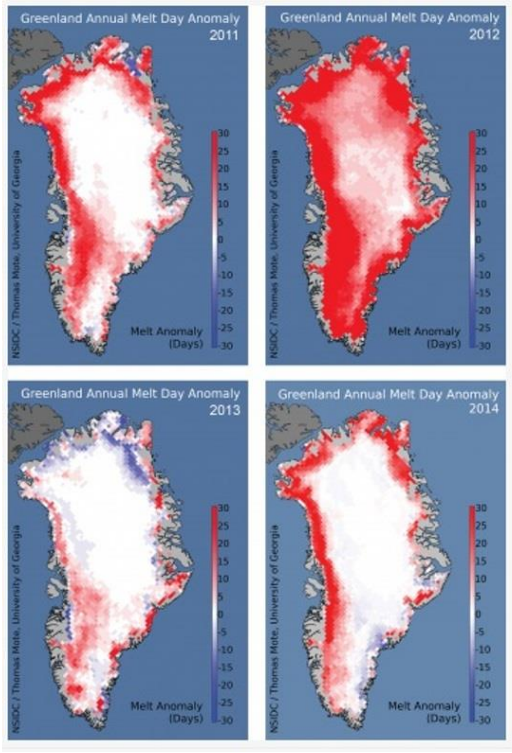

Figure 3. Greenland's annual melting day anomaly 2011-2014 (Source: National Snow and Ice Data Center/Thomas Mote, University of Georgia, http://nsidc.org/greenland-today/2015/01/ accessed Jun 09, 2016)

The First Law of Thermodynamics and Space Debris

In its simplest form, the First Law of Thermodynamics states that neither matter nor energy can be created or destroyed. The amount of energy in the universe is constant. This law will be better understood if we give a wider range of examples. Let us look at satellites to see how we can prove the validity of this law. Consider a satellite in its orbit. Why does this "perpetual motion" not contradict this law? The students will probably give the right answer immediately that the satellite does not stay in its orbit forever; sooner or later it enters the Earth's atmosphere due to friction, and after it burns out. With this connection we can mention the problem of space debris.

The satellite's return into the atmosphere and its annihilation, however, can be a very long process. Therefore, there may be satellites which no longer function but might stay in orbit for years, even decades. An interesting example of this is the ENVISAT, an Earth-monitoring satellite of ESA, which will be a ghost in space for 150 years. This problem is a new challenge for space research in the twenty-first century; it is necessary to deal with the increasing number of space debris. Considering the data of 2016 [3], there are more than half a million pieces of space debris of varying sizes. It is worth mentioning this in physics class; certainly there are students who would be fascinated by space debris.

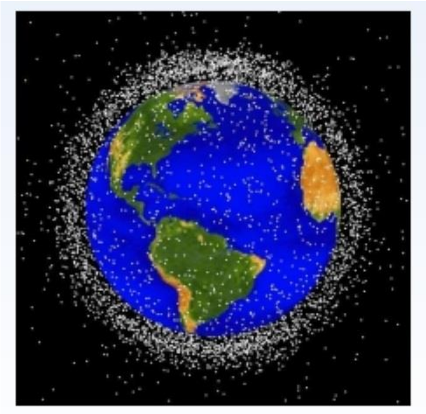

Figure 4. Space debris detected around the Earth (larger than 5cm in diameter). (Sources: [4])

The website of ESA features an article that describes how ESA is trying to work out a method to capture satellites. In this method, they would use harpoon to capture an ungovernable, dysfunctional spacecraft. The question that also might arise in the student is this: what would happen if these spacecraft collided? In spite of the incredibly enormous quantity of space debris, calculations support that the probability of collision is very little. When I talk about this in class, I show an article to the students detailing an unprecedented, serious space collision. It happened in 2009 when a commercial Iridium communications satellite and a defunct Russian satellite collided above northern Siberia.

Closing Remarks

I have been using examples from space research in my teaching for many years, always changing and expanding the references in order to make the subject of physics more colourful. Since I started to use this method, several students of my classes have done research in the topic of space technology and have taken part successfully in the ‘Physics in Science and Arts Competition’, in spite of the fact that they study to be professional musicians. This competition is a good possibility for another learning pathway. Nowadays it is important, that the education of physics will not only happen in the classroom, but will also happen in other places. For example I visited with my students the control centre of MaSat-1 at the Budapest University of Technology and Economics and we have listened to a presentation about MaSat-1given by a university student.

I believe it is important that students learn more about space research even if they go into a completely different field of study, since in this day and age, this area plays a bigger and bigger role in our everyday life.

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