

1 General Remarks

1.1 Energy and power

One may find many different definitions of the notion of energy in various sources. Not exactly "different", they are all equivalent – it's the wording that is different. I think that the best textbook definition is a simple one, and I will combine the wording from [an Wikipedia article](#) with some extra comments of my own "additions":

In physics, energy is the property that must be transferred to an object in order to perform work on or to heat the object, and can be converted in form, but not created or destroyed.

OK, for me everything is correct in the above definition – with the exception that I would prefer energy be referred to as an "entity", rather than as a "property". Entity means "something that exists", whereas property, according to the dictionary, is "an attribute, quality, or characteristic of something". What I don't like is this "of something". The term "property" in Wikipedia definition implies therefore that energy is always associated with an **object** – it has to be contained by an object, or transferred from one object to another. In fact, it is "almost always" the case, but there exist some "exotic situations" in which it is not easy to identify "the object". For instance, energy – in the form of radiation, such as, e.g., the

solar light – is able to travel through empty space. In other words, energy may exist in empty space, or may fill a region of empty space – and is empty space an object? From the viewpoint of advanced modern physics, a firm **no!** is not a good answer to this question. According to modern theories, vacuum is – let me quote a statement I've found in [Physics Forum](#) – "very much alive and kicking". Well, but all this "life" is only a **virtual** one – we cannot see it, even with the help of sophisticated modern measuring devices. So, if we appeal to our "conventional wisdom", calling "empty space" an object would be a bit weird. As will also be calling energy flowing through vacuum "a property" of this vacuum. But if instead of "property" we agree to use "entity", the problem automatically disappears. Energy travels through vacuum, so it does exist in vacuum it travels through – and "entity", as said above, is "something that exists". Now everything is OK!

Actually, whether we should say "entity" or "property" is rather a linguistic dilemma, it's really not so important. One can even think of it as an example of *tetraphyloctomy* – it's a Greek term coined by the famous writer Umberto Eco, meaning "splitting a hair in four", or paying too much attention in scientific disputes to details that are of little importance, or totally irrelevant. In fact, what is really relevant, is to under-

stand what energy is. Let's then analyze the Wikipedia definition in closer detail.

1.1.1 Energy Conservation

Let's start with the following statement: *energy... ...can be converted in form, but not created or destroyed.* Very important! Energy cannot "pop out of nothing" (with the exception of Harry Potter movies), it cannot disappear without a trace. This expresses a law, known as the Energy Conservation Law, one of the most fundamental laws of physics. Energy may be passed from one object to another, but the sum of energies in all objects under consideration remains unchanged. In other words, some objects may become "energized", while some other "de-energized", with the total energy unchanged in the process. Also, as was argued above, energy from one object must not necessarily be transferred to "another object", it may be "radiated out", i.e., it may leave the first object in the form of radiation and then travel through empty space. However, the energy of the radiation "sent out" must be exactly equal to the amount of energy lost by the object from which the radiation is emitted. 1

1.1.2 Energy and Work

In the Wikipedia definition quoted at the beginning it is stated that: *energy... ...must be transferred to an object in order to perform work on... ...the object.* Let's recall what "work" means in physics. Actually, physics recognizes several different types of work – but one of them, the **mechanical work**, is of special importance. Suppose that a body is at rest at a initial position x_i . Then, a force F is exerted to it for some time, and as the result of it the body is displaced to a new "final" position x_f . We will call the difference

$$\Delta x = x_f - x_i$$

the *displacement*, and the product of Δx and the force F :

$$\Delta W = F \cdot \Delta x \quad (1)$$

is the mechanical work performed in the process of shifting the body.

Performed by whom or by what? Well, we don't need to specify, it's enough to assume that there was an *object* capable of exerting the force F on the body. Initially, this object contained certain amount of energy, E_i , and after the work was performed, this amount changed to a final lower value E_f . So, the difference:

$$\Delta E = E_f - E_i$$

is the energy the object "paid" for performing the work. This is obviously a negative number, right? And

now we have reached a very important point – namely, a declaration that is known as the *Work-Energy Theorem*, or the *Work-Energy Principle*, or even by longer name: *The Principle of Equivalence of Work and Energy* – and it simply states that:

$$\Delta W = -\Delta E$$

(note that ΔE is a negative number, so the minus in the above equation is needed to obtain a positive work). In other words, the above principle simply states that for performing work, the “performer” has to pay an equal price in energy. It also works the other way around: for increasing the energy of an object by ΔE , one has to “pay the same price” in work.

1.1.3 Energy Units

It was said above that the mechanical energy is of “special importance” in physics. Why? Because the most important energy unit used in physics, the **Joule**, is defined as – let’s again quote [Wikipedia](#) – *the energy transferred to (or work done on) an object when a force of one newton acts on that object in the direction of its motion through a distance of one meter.*

But why is it “the most important”? Well, the thing is that in modern physics there are special regulations, known as the “SI system”, stating that the units of all quantities used in physics should be defined in terms

of seven **base quantities**. Three of these seven are the units of length, the meter (m), of mass, the kilogram (kg), and of time, the seconds (s). For more details, please look at a [NIST Web page](#) (NIST = National Institute of Standards and Technology).

So, the SI unit of force is a Newton:

$$1\text{N} = 1 \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \quad (2)$$

Why such a second combination? In short, it all comes from something known as “the Second Newton’s Law of Dynamics”. And how it comes? Well, I think that rather than explaining it step-by-step, I should give you a link to a good [Internet source](#). And if you don’t yet have an idea “how big” the force of 1 N is, I can tell you that the weight of something with the mass of **one pound** is approximately 4.5 N; and of 1 kilogram mass, about 9.81 N.

Now, once we know the SI unit of 1 N, we can readily find the SI unit of a Joule:

$$1\text{J} = 1\text{N} \cdot 1\text{m} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} \quad (3)$$

r

1.1.4 Power

If energy is transferred from one object to another (e.g., for performing work), it is not only important to know *how much* energy is passed, but it

may also be essential to know *how fast* this energy is delivered. So, there is a special unit describing *the rate of energy transfer*, called **Watt**. Its symbol is “W”, and it’s defined as the transfer of one Joule per one second:

$$1\text{W} = \frac{1\text{J}}{1\text{s}} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^3} \quad (4)$$

e number of rev

1.1.5 Energy expressed in terms of power

The Watt and its derivatives (1 kW = 1000 W; 1 MW = one million Watts; or one miliWatt = 1 mW = 0.001 W) are familiar and often , used units. The notion of power readily appeals to one’s imagination. If you hear someone says: “This is a 60 W light bulb”, or “I have purchased a new 10 kW air conditioner for my house ”, or “The power of the new Conda Hivic’s engine is 150 kW”, you usually know immediately what this person is talking about.

In contrast, the Joule is a ”much more abstract” unit. If one says: “This light bulb has consumed 216 000 Joules of energy”, you have to think for a moment or even longer to figure out what the person is talking about. Even though it’s simple – a 60 W bulb uses 60 Joules every second, so over one hour it used $60 \text{ J/s} \times 3600 \text{ s} = 216\,000 \text{ Joules}$.

Therefore, convenient way of describing energy transfer is not to use Joules, but an equivalent unit based on the Watt, called ”Watt second”, with the symbol Ws, W-s, or W·s. One Watt-second is the amount of energy delivered by a source of 1 W power over the period of 1 second – so, it’s indeed the same as 1 Joule. A derivative unit is the Watt-hour, Wh or W-h, equal to 3600 Joules; and perhaps the most often used energy unit in everyday life, the kiloWatt-hour, kWh = the energy delivered by a source of 1 kW power over the period of one hour = 3,600,000 J. Look at the bill the power company sends to you – you pay for kiloWatt-hours, not for Joules. From the Web, you may learn that in the year 2015 an average american household consumed 10.8 kWh per day, or 901 kWh per month. Simple? – well, definitely simpler to comprehend than if the same Web source said: “3,243,600,000 Joules per month”.

1.1.6 Forms of Energy: Physics

In “pure physics”, we essentially recognize two basic types of energy – potential and kinetic.

Potential Energy is any form of energy that can be “stored” by a physical system – for instance, the energy of a stretched spring, a body in a gravitational field, or the energies of some physical fields. The name comes from

the fact that such energies, essentially, can be stored for an unlimited time, and then converted to work or other energy form at a chosen moment of time. One can then think of such systems “pumped” with energy as of those that “have a potential”.

The energy of a stretched or compressed spring can be readily calculated, based on the Hooke’s Law that describes the relation between the extension (a.k.a. elongation) of a stretched spring, or the contraction (a.k.a. shortening) of a compressed spring, and the “restoring force” F , i.e., the force tending to bring the spring back to its original length:

$$F = -k \cdot \Delta l \quad (5)$$

where Δl is the change in the spring length (positive for extension, and negative for contraction), and k is the so-called “stiffness constant” of the spring; the minus sign reflects the fact that the restoring force is always oriented towards the equilibrium position, so its sign is always opposite to the sign of Δl .

Knowing the force, we can readily calculate the work that has to be performed for stretching/compressing the spring by Δl . For such an action we need to apply a force which overcomes the “restoring force”, i.e., which points in the opposite direction. Since the force needed is not constant, but it changes during the process, we cannot use a simple multiplication as in

Equation (1). We have to integrate:

$$\begin{aligned} \Delta W &= \int_0^{\Delta l} F(l)dl = \int_0^{\Delta l} kldl \\ &= \frac{1}{2}k(\Delta l)^2 \end{aligned} \quad (6)$$

Now, invoking the Work-Energy Principle, we can conclude: *The amount of potential energy¹ stored in the stretched spring considered is:*

$$\Delta V = \frac{1}{2}k(\Delta l)^2. \quad (7)$$

We will not talk about the energy of stretched springs (or “elastic energy”) in this course, but I presented it here because it’s a very instructive example of using the Work-Energy Principle and showing how one can “store” potential energy in a system.

Another good example is the potential energy of a lifted object of mass m . The force of gravity acting on such an object is $F = mg$, where $g = 9.81 \text{ m/s}^2$ is the acceleration due to Earth’s gravity. The force is constant, we don’t need to integrate – so if we lift the mass from the height H_i

¹I use V as the symbol of potential energy, but in other books or Web sites you may find different symbols. The same is true for many other quantities in physics. The thing is that there are many more quantities of interest in physics than available Roman and Greek letters. Therefore, the same letter is often used for several different things – e.g. V is also used for volume, velocity, voltage and perhaps several other quantities.

to the height H_f , we do work $\Delta W = mg(H_f - H_i)$. So, again invoking the Work-Energy principle, we have shown that by lifting the mass we have increased its potential energy by:

$$\Delta V = mg(H_f - H_i) \quad (8)$$

A lifted object can be then used as an “energy reservoir”. Actually, such method is used for storing huge amounts of energy in facilities known as “Pumped Storage Hydroelectric Power Plants”, about which we will talk later, in a section titled ”Hydroelectric Power”. They store energy not by lifting a solid object of mass m , but by pumping water from a lower tank to a higher tank – but the general principle is the same.

Kinetic Energy. It’s the energy of a moving object, executing a *linear* motion or a *rotational* motion. For a solid object of mass m moving with a speed² of v the formula for kinetic energy is:

$$K = \frac{1}{2}mv^2 \quad (9)$$

²Note that as a symbol of speed we use the same letter as we have used a moment ago for potential energy – but now we use **a small letter** for distinction. By the way, in “professional slang” big (capital) letters and small letters are often referred to as, respectively, “upper case letters” and “lower case letters”. Why? For historical reasons! You may find an explanation, e.g., in this [Web document](#).

Moving fluids or gasses also carry kinetic energy, but the appropriate mathematical formulae are more complicated – actually, about the kinetic energy carried by a moving gas (air) we will talk in the section “Wind Power”.

Kinetic energy in linear motion can hardly be used as a practical means of storing energy, because if one tried, the “reservoir would run away” :-). However, this is not the case with kinetic energy of *rotational motion*, i.e., of spinning object.

The kinetic energy of a spinning rigid solid body is given by:

$$K = \frac{1}{2}I\omega^2 \quad \text{with} \quad \omega = 2\pi f \quad (10)$$

where f is the number of revolutions per second executed by the spinning body, and I is a quantity called *the moment of inertia*, which depends on the mass, on the shape, and on the dimensions of the body in question. The formulae for moments of inertia of bodies of many different shapes can be readily found in the Web, for instance, in [this Hyperphysics Web site](#).

In contrast to bodies moving along straight trajectories which are rather useless from the viewpoint of energy storing, spinning bodies can be used and **are widely used** for such storing. Such bodies are commonly known as “flywheels”. If a flywheel spins too fast, it may be torn apart by centrifugal forces – therefore, the amount of energy that can be stored by a fly-

wheel is not spectacular. One interesting idea that emerged in the middle of the last century was to use flywheels in public transportation, for propelling buses. After the flywheel in a such vehicle, called a “gyrobuses”, was “charged with energy” by an electric motor, it could run up to 6 km (about 3.5 miles). An advantage of gyrobuses was that they were very “clean”, they emitted no fumes, in contrast to buses propelled by Diesel engines. However, there were many problems with maintaining fleets of such vehicles, so the initial enthusiasm gradually died out, and the several existing Gyrobus service systems in Europe and Africa were shut down by the end of the 1950-s.

Oscillator energy The energy of simple oscillating objects, such as a pendulum, a weight suspended on a spring, or a vibrating guitar string is worth taking a closer look at, even though such things have no direct application in the grand-scale energy usage that is the main subject of this course. Namely, in the oscillating system mentioned above one can clearly see the processes of converting one form of energy to another. Consider a simple pendulum, i.e., a weight of mass m suspended on a piece of a light string. Pull the weight to the right from the equilibrium position, as shown in [this short video clip](#). By doing that, you “charged” the mass m with potential energy ΔV , because

it’s now slightly higher than it was at the equilibrium position. Now, you let it go – and the potential energy starts gradually changing to kinetic energy. When the mass passes through the equilibrium point, all the acquired potential energy is gone, it has been entirely converted to kinetic energy. **By the way, here is a small challenge for you:** you may use $K = \Delta V$ and process it further in order to find the speed v of the mass m when it passes through the equilibrium point – assume that the length of the pendulum string is, say 1 meter, and in the initial displaced position the string made an angle of 20 degrees with a vertical line; please try, it’s a good exercise. I am not giving you the value of m because, as you will find out, you don’t need to know it. It’s a good exercise – and if you have a major problem with obtaining the solution, it will probably mean that you may need some extra studying of very elementary physics in order to do well in this course).

Back to the pendulum: after the initial potential energy is totally lost and totally converted to kinetic energy at the instant of passing through the equilibrium point, the pendulum continues its swing motion, but now the kinetic energy is gradually converted back to potential energy. The process lasts until the pendulum reaches the maximum displacement angle, equal to the initial displacement angle – but

now to the left. At this instance, the kinetic energy is totally gone, the speed of the mass m becomes zero again, and the initial potential energy ΔV is totally “regained”. And from this moment on, the process described above restarts, and runs in the opposite direction. A full swing from the right to the left and back to the right is called “the oscillation cycle”, and the time it takes to make such a full cycle is called “the oscillation period”.

In the vibration of a guitar string, or in the oscillations of a blob suspended on a spring, you have exactly the same periodic process of conversion of potential energy to kinetic energy and back to potential energy. Yet, as mentioned above, the oscillations of such objects do not play any significant role in the grand-scale energy usage, why do we talk about them over here? Well, the reason is simple – because the energy of oscillations of **atoms** in solids, the sum over all atoms, is what constitutes the **thermal energy** contained in such objects.

Thermal Energy and Heat. The question of what makes objects hot in some circumstances, and cold in some other situations, had intrigued philosophers³ for millennia. In the

³in the old days, there were no “scientists” of different categories, all people doing any kind research were called “philosophers”, what in ancient Greek language

XVIII Century, a well-established theory was that the entity responsible for such effects was a mysterious *caloric fluid* – an invisible, weightless and odorless substance, capable of penetrating matter. An object with high content of caloric fluid would get hot, and an object depleted of it would become cold. Only in 1799 a British scientist Humphry Davy performed a famous experiment showing that bodies may be heated up by *performing work on them*, which some time later led to the formulation of modern theory of thermal phenomena, usually referred to as *thermodynamics*. As we know now, it’s not the caloric fluid that makes bodies hot – it’s the *internal energy*, or *thermal energy*. It’s a special category⁴ of energy, usually denoted as U for distinction from pure kinetic energy or potential energy.

Only in diluted gases their internal energy can be identified with pure kinetic energy – here U is the sum of the kinetic energy of all individual molecules comprising the gas. In solids, in contrast, all constituent atoms are at fixed positions, they cannot move freely. However, each atom is coupled to several neighboring atoms by

meant “they who love wisdom”

⁴Also, a very important category in the context of energy usage, because most of the electric energy consumed today comes from *thermal power plants*, i.e., from big facilities in which thermal energy is converted to electric energy.

“bonds”, which act as springs of sub-nanometer lengths. Therefore, each individual atom behaves like a miniature spring oscillator. Then, the U of a given solid is simply the sum of the oscillatory energy of all individual vibrating atoms (more often, we call it *vibrational energy*).

So, it is the energy which decides of whether a body is hot or is cold. The internal energy of a body, call it A, can be changed in two ways. One is, as Humphry Davy discovered, by performing work on the body. For the amount of work performed, we use the symbol ΔW . The other way is by *heat transfer* from another body call it B, brought in contact with body A. If B is “warmer” than A, some energy flows into A, and if B is “cooler” than A, some energy exits A and flows into B. The portion of energy entering or exiting body A in such a way is called *the heat transfer*, and conventionally denoted as ΔQ . What we have stated above by words, can be expressed in a mathematical form:

$$\Delta U = \Delta W + \Delta Q \quad (11)$$

which is known as the **First Law of Thermodynamics**.

Two comments concerning the above. One is simply about the terminology. According to the “official language of thermodynamics, we cannot say: *It’s the heat content that decides of whether the body is warmer*

or cooler. The correct way is to say: *It’s the amount of internal energy in a body which decides of wheter it is warmer or cooler*. The term *heat* should be used only for describing the amount of thermal energy transferred into the body, or out of the body, via contact with another body.

The other comment is about physics. Namely, consider a situation in which there is no heat transfer, $\Delta Q = 0$, only work ΔW **is performed on the body**. Then, according to the First Law, the content of the internal energy in the body increases by:

$$\Delta U = \Delta W \quad (12)$$

Seems in perfect agreement with the Work-Energy Principle? Yes, it is!

But now one can think simplemindedly: if so, then the First Law may work in the other way, namely:

$$\Delta W = \Delta U \quad (13)$$

Meaning that the body can deliver work of ΔW by diminishing its internal energy by ΔU – which also seems to be in perfect agreement with the Work-Energy principle!

But the bad news are that the First Law **does not** work the other way ;-(... Thermal energy cannot be converted to mechanical work directly... The troublemaker here is an entity called *Entropy*, which emerges only in the **Second Law of thermodynamics**.

We will talk about the Second somewhat later – because now we have to introduce one more essential thermodynamic parameter – namely, the *temperature*.

Temperature. We all have an intuitive concept of temperature, based on – quoting the words of Herbert Callen⁵– *psychological of hot and cold*.

It’s also a common knowledge that “temperature is what you read from a thermometer”. It is not silly – it’s something we call “an operational definition”. Sometimes it is really difficult to find something better than such a definition for notions in physics. For instance: “Time is what we read from a clock” – can you think of a better definition of time? It’s certainly not easy!

So, in low-level courses of physics instructors or textbooks often determine that such an “operational definition” of temperature is sufficient – with additional information about “standard temperature points” needed for calibrating the thermometer. In the Celsius scale, created in 1742, such points are the water freezing temperature, taken as 0 degrees, and water boiling temperature, taken

⁵Herbert Callen, 1919-97, was a distinguished American physicist, author of the textbook *Thermodynamics and an Introduction to Thermostatistics*, the most frequently cited thermodynamic reference in physics research literature.

as 100 degrees. Mr. Fahrenheit, who created a temperature scale even earlier, in 1724, took the temperature of human body as 100 F, and in the Celsius that of the mixture of ice and ammonium chloride as 0 F. Those points were not very precise, so later people started using the same points as in the Celsius scale: water freezes at 32 F, and boils at 212 F. Therefore, the conversion formulae between the two scales are:

$$t_{\text{Fahr.}} = 1.8 \times t_{\text{Cels.}} + 32F \quad (14)$$

and

$$t_{\text{Cels.}} = \frac{5}{9} \times (t_{\text{Fahr.}} - 32F) \quad (15)$$

However, I can bet that you don’t want to think that you are taking only a “low-level physics course” – and you’ll certainly like to know more, what is the **underlying physics** in the notion of temperature. Well, to satisfy your wish may not be an easy task for an instructor... The think is that with the progress in physics, when more and more experimental facts were collected, and more and more understanding of them was achieved, the definition of temperature also “evolved” to be consistent with all the accumulated knowledge of thermal phenomena. And presenting the current “state of the arts” definition would be difficult, for two reasons. First, because it involves the notion of *Entropy*, which

is a highly abstract concept. And second, because the definition in question is given by a mathematical equation including **partial derivatives**. Well, my intention is to make the present text “digestible” even for students who have not necessarily taken any **calculus classes**, and therefore I try to seldom use even the **simple derivatives**, only when there is really no other option – but the theory of partial derivatives, it’s a much more advanced math than the theory of simple derivatives!

Therefore, I will not even try to discuss this super-duper “state of the arts” definition here, but I will give you a definition that is perhaps not perfect, but definitely is good enough in the temperature region around the room temperature, and for higher temperatures. Which is OK, because in this course we won’t be talking of any phenomena that occur in the region of very low temperatures! And one more advantage is that the definition that will follow is primarily a “conceptual one”, with no much math.

The definition is based on the so-called “kinetic thermodynamics”, a theory that matured in the second half of the XIX Century. Please recall what was said above about the internal energy U of diluted gases: it’s simply the sum of the kinetic energies of all molecules comprising the gas considered. And what we said about the the energy U in solids? That it is the sum

of **vibrational** energies of all atoms in the solid.

Now, remember what happens in vibrational (oscillatory) motion of a spring oscillator: the potential energy of the spring V_{stretch} changes to kinetic energy K , K changes to potential energy of the compressed spring V_{compr} , the latter back to K , K back to V_{stretch} , and then the cycle repeats, and so on, and so on. From the above it follows that per average, “half of the time” the oscillator energy is potential, and “half of the time” it is kinetic. And averaged over a long time, the “potential energy contribution $\langle V \rangle$ ”⁶ and the “kinetic energy contribution” $\langle K \rangle$ are equal: So, we can write that the total energy of a spring oscillator is:

$$E_{\text{Oscill.}} = \langle V \rangle + \langle K \rangle \quad (16)$$

But also:

$$\langle V \rangle = \langle K \rangle \quad (17)$$

So that:

$$E_{\text{Oscill.}} = 2\langle K \rangle \quad (18)$$

In view of the above, since a solid may be thought of as an assembly of miniature “atomic oscillators”, we can conclude that the thermal energy U of the solid is:

$$U_{\text{solid}} = 2\langle K_{\text{all atoms}} \rangle \quad (19)$$

⁶In physics, writing a quantity in between angular brackets: $\langle \text{quantity} \rangle$ is an often used symbol of averaging.

In conclusion, we can say that both for a gas and a solid:

$$U \propto \langle K_{\text{all atoms}} \rangle \quad (20)$$

where the meaning of the mathematical symbol “ \propto ” is “proportional to”.

Now, it can be further reasoned:

more $U \Rightarrow$ warmer body \Rightarrow higher temperature;

and

less $U \Rightarrow$ cooler body \Rightarrow lower temperature,

which lead to the final conclusion:

The temperature of a body is a measure of the average kinetic energy of constituent atoms. We are nearly done with temperature! But before we finish, I need to tell you about two important conclusions emerging from the considerations in this sub-sub-sub-section. The first conclusion is that the internal energy U is a linear function of the temperature, which we will denote now as T . “Linear function” simply means that the dependent value (U in the present case) is equal to the independent value (here, the T) multiplied by a constant factor. So:

$$\begin{aligned} U_{\text{given body}} &= \text{constant factor} \cdot T \\ &= C_{\text{given body}} \cdot T \end{aligned} \quad (21)$$

where the C coefficient is called the “heat capacity” of a given body.

The second conclusion is that if all internal energy is removed from the body, i.e., when $U = 0$, then it must be $T = 0$. Indeed, zillions of experiments carried out since the birth of modern thermodynamics have made it possible to determine that such a temperature point does exist, at -273.15 °C, or -459.67 °F. This point is called the “absolute zero”. The SI system introduces yet another temperature scale, called the “Absolute Temperature Scale”, or the “Kelvin Scale”, in which the absolute zero is the fundamental thermometric point. It was decided, for simplicity, that one degree in the Kelvin scale, 1 K in short (without the “°”) would be equal to 1 °C, one degree in the Celsius scale. So, the conversion from the Celsius scale to Kelvins is pretty straightforward:

$$T[\text{K}] = t[^\circ\text{C}] + 273.15\text{K} \quad (22)$$

([...] means “in the units of”, of what is written between the two brackets). Hence, water freezes at 273.15 K, and boils at 373.15 K. For distinction, capital T should be used only for expressing temperatures in Kelvins, and lowercase t for temperatures in the Celsius or Fahrenheit scales. Please always pay attention to in which scale the temperature is given, confusing °C with K is one of the most common

errors made by students in homeworks and exams in the Ph313 course!

1.2 Forms of Energy and Power: an Engineer's Approach

The “Energy Alternatives” topic depends much more to the realm of engineering sciences, than to the realm of “pure physics”. We needed to start with introducing a number of important physical concepts (and we will once in a while return to “pure physics”), but now we will switch a mode that is much closer to an “engineer’s approach”.

We have to begin with classifying energy forms according to the “sources they come from”, rather than their physical nature. And below there is a list of energies and their sources we will discuss throughout the present course. The items are listed in “chronological order”, beginning with the energies utilized by the most ancient civilizations, and ending with power sources that have only been most recently harnessed. The list is shown in the form of two slides, which will show up when you click on the blue clickable links (such a method allows to use them also in classroom presentation – from now on, most graphic material used in this e-book will be shown in the same way).

More about temperature – only if you are interested, no need to read, no questions related to the framed text in the exams.

The “kinetic thermodynamics based” theory of temperature I have outlined on pp. 11-12 – in particular, the Eq.(21) – looks reasonable, and it is taught even in some introductory-level physics courses. In the middle of the XIX Century the kinetic theory was considered as remarkably successful, because its predictions were found to be in a very good agreement with experimental results. But in the early 1880s a team of Polish scientists, K. Olszewski and Z. Wroblewski, carried out the first historical liquefaction of air – which opened the door to “low-temperature physics”. Experiments performed in the following years demonstrated that the heat capacity of solids, predicted to be a T -independent constant by kinetic thermodynamics, actually showed a dramatic decrease in the low- T region. A new much more sophisticated theory explaining such anomalies was created in 1907 by Albert Einstein. His theory also showed that the temperature has to be defined in a new, more complicated way. But the results of kinetic theory are OK at room temperature and higher T -s, and therefore it's acceptable to use them in this T region. In addition, the kinetic theory is pretty “pedagogical”, and hence it is still being taught in academic courses of introductory level.

I propose that we order our list according to the time in history when humans started using a given form of energy at a meaningful scale:

- **“Biological energy”** – the energy stored in our bodies. Humans started using this form of energy long before they became humans (for moving around, climbing trees, hunting, fighting...).
- **Solar energy** – same as above. E.g., to get warm after a chilly night.
- **Chemical energy** – that stored in the food. Again, humans started taking advantage of this form long before they became humans.
- **Thermal energy** – that from fire. At the onset of civilization! It was the first form the use of which required human intellect!
- **“Animal energy”**: here we mean “biological energy”, but that stored in the bodies of domesticated animals, not our own bodies.
- **Wind energy** – first ever “hi-tech” devices built by humans used it! In sailing boats, wind mills, simple water pumps for irrigating fields.
- **Hydro-energy** – kinetic/potential energy of water in streams and artificial ponds – probably, started being used about the same time as wind energy. Ancient civilizations, e.g., Egyptians, used both!

Then, there was a long period with no significant progress in using new energy forms...

**... Things started moving in fast pace only in the Second Millennium.
The new forms that people employed then were:**

- **Chemical energy from “synthetic”, i.e. man-made carriers:**
gunpowder (a.k.a. “black powder”), first invented in China about 1000 years ago, was perhaps the first?
- **Chemical energy from mined sources** (e.g., coal): widespread use begun in XVIII Century; then (XIX Cent.) came oil, and natural gas.
- **Energy from heat engines** – when coal became available; the first heat engine was built in England by Newcomen in early 1700-s then a far better machine was built about 50 years later by James Watt. When that happened, the “Industrial Revolution” began!
- **Electrical energy** – XIX Century; the proud XIX-century people called their times *The Century of Steam and Electricity*.
- **Geothermal energy** – water from hot sources had been used for millennia by people who dwelled nearby, but a utilization on industrial scale began only in the early years of the XX Century.
- **Atomic (nuclear) energy** – first used for not-so-nice purposes in 1945, for peaceful purposes a few years later.
- **Mass**, as discovered by A. Einstein, is also an energy form ($E=mc^2$).
- **Future**, not yet known usable forms????
- **Is this list complete? Can you think of any other items?**