Elements of artificial intelligence in computer calculations of physical quantities

At present, the conduct of engineering, scientific, technical and feasibility calculations on a computer may be based on physical quantities [1-3], not just not on numerical values. This simplifies and speeds up calculations, reduces the likelihood of errors in them, and increases the "readability" of calculations. Programs such as Mathcad, Maple Flow, Python, SMath, etc. are equipped with this toolkit. Such computing tools need to be improved with the connection of artificial intelligence (AI) elements to them. This will be discussed in this article through the analysis of a number of examples. The article can be considered as a kind of technical task for the creation of an artificial intelligence system in computer calculations of physical quantities.

Consider the stated goals point by point.

1. Working with different physical quantities that have the same units of measurement

Figure 1 shows a fragment of the calculation of a combined cycle power plant with two working fluids - air / flue gases and water / steam. The flue gases leaving the combustion chamber of the gas turbine plant (air and fuel compressed in the compressor are fed into it) are sent to the gas turbine, which drives the rotor of the first electric generator. Then the flue gases enter the steam boiler (waste heat boiler), the steam from which is sent to the steam turbine, which drives the rotor of the second electric generator. The efficiency of such a binary power plant is significantly higher than that of a separate gas turbine or steam turbine plant.

The mass specific work of a steam turbine - the work of one kilogram of water vapor (lst) is calculated as the difference in the specific mass enthalpy[1] of steam at the inlet (hst1) and outlet (hst2) of the steam turbine. A similar calculation is shown for the gas turbine. In the formulas, the units are included. The AI system that supports this dimensional calculation has added a constant C to the answers, the meaning of which will be explained below in the next paragraph.

[1] From the ancient Greek ενθαλπω - "I heat." Other names are thermal function, Gibbs thermal function, heat content, isobaric-isoentropic potential. Equal to internal mass specific energy plus product of mass specific volume and pressure.

Gas turbine specific work

$$l_{gt} := h_{gt1} - h_{gt2} = 692.2\ \frac{kJ}{kg}$$

где $h_{gt1} = (1483 + C)\ \frac{kJ}{kg}$

$$h_{gt2} = (790.8 + C)\ \frac{kJ}{kg}$$

Steam turbine specific work

$$l_{st} := h_{st1} - h_{st2} = 1332\ \frac{kJ}{kg}$$

где $h_{st1} = (3336 + C)\ \frac{kJ}{kg}$

$$h_{st2} = (2004 + C)\ \frac{kJ}{kg}$$

$$l_{gt} + l_{st} =$$

Units?

The ratio of gas and steam consumption

$$m := 8.2649\ \frac{kg}{kg}$$

$$m \cdot l_{gt} + l_{st} = 7053\ \frac{kJ}{kg}$$

Fig. 1. Two different physical quantities with the same units of measurement

An attempt to add up the specific work of two turbines - gas and steam - ended in failure with an error message. The fact is that a kilogram of gas and a kilogram of water vapor are associated with different physical quantities, the values l_{gt}, l_{st} which cannot be added. Another value m (circulation ratio) appears in the calculation - the ratio of gas flow to water vapor flow. Usually this value is taken to be dimensionless, but this is not the case. This quantity has a dimension - kilograms divided by kilograms, and these two units of mass in a fraction cannot be reduced. In [4], it is shown how the problem of different physical quantities with the same units of measurement can be solved through the use in the calculation of the unit of measurement of a physical quantity that is not involved in this calculation - candela, for example. The mass of gas is measured in kilograms, and the mass of water and water vapor in candela. But this is inconvenient, since you have to constantly correct the unit of measure in the answers. The solution to the problem can be this - see fig. 2.

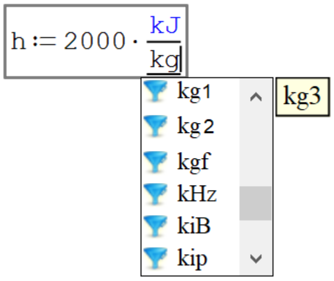


Fig. 2. Entering into the calculation of the same units of measurement of different physical quantities

In the SMath environment, pressing the letter k or another letter on the keyboard leads to the appearance of a drop-down list of all user-defined and built-in variables and functions whose name begins with this or another letter (see also Figure 5). Entering the next letter shortens this list, leaving only the names of those identifiers that begin with these two letters, and so on. This is very convenient when doing even simple calculations. But such hints can be removed if desired. So, in such a list, after pressing the letters k and g, not one, but several units of mass kg may appear, associated with different physical quantities that cannot, for example, be added - see fig. 1. These different kilograms may or may not be in different fonts, as shown in fig. 1.
If a combination of different units of measurement is introduced - the same kilojoules divided by kilograms, then it should additionally be noted what physical quantity is entered into the calculation - internal specific mass energy, internal specific mass enthalpy, or something else. All these are different physical quantities that cannot add up, for example. The specific mass energy can also be introduced with the extremely simplified unit m^2/s^2 (see Fig. 5 below). But if at the same time it is noted that this is precisely the specific mass energy, then everything will fall into place.

Conclusion on point 1. An AI system that supports physical quantities in calculations should prompt the user that the same units can be assigned to different physical quantities..

2. Constant in numerical answers

In Figure 1, under the subtraction of two values, is written what the individual values are. The constant C appears in the answers, analogous to the added constant we include when taking an indefinite integral analytically. This constant indicates that the value of the specific enthalpy itself does not have any physical meaning - only the difference of these values has meaning, in which two identical constants cancel out. For readers who are not related to heat engineering and have not encountered enthalpy, let's say that enthalpy, otherwise heat content, is the sum of internal energy with the product of the specific volume and the pressure of the working fluid - flue gas or water and water vapor. A mechanics example might be that of a flying stone that has two types of energy - potential and kinetic, the sum of which gives the total energy (enthalpy, "energy content") of the stone. When printing the numerical values of these two energies, the kinetic energy should be printed without any constant, and the potential energy with a constant.

However, at the request of the user, attributing a constant to the answer can be excluded. So experienced users, through a special switch in the SMath environment, can disable the drop-down of lists, which is shown in Fig. 2 and 5.
Before drawing a conclusion on item 2, we note two points in Fig. 1.

First. Some unspoken standards for the design of calculations require that, before deriving a numerical answer, the formula by which the calculation was carried out should be duplicated so that instead of just the variable names, their numerical values are shown; as illustrated in Fig. 3.

Удельная работа газовой турбины

$$l_{gt} := h_{gt1} - h_{gt2} = 1.483 \cdot 10^{6}\ \frac{J}{kg} - 7.908 \cdot 10^{5}\ \frac{J}{kg} = 692.2\ \frac{kJ}{kg}$$

Fig. 3. Substitution of numerical values in the formula (SMath)

In the Mathcad environment, such a substitution can be done through the "*explicit*" symbolic operator - see fig. 4.

$$l_1 := 120\ cm \qquad l_2 := 5\ ft$$

$$l := l_1 + l_2 \xrightarrow{explicit,\, l_1} 120\ cm + l_2 = 272.4\ cm$$

$$l := l_1 + l_2 \xrightarrow{explicit,\, l_2} l_1 + 5\ ft$$

$$l := l_1 + l_2 \xrightarrow{explicit,\, ALL} 120\ cm + 5\ ft = 8.937\ ft$$

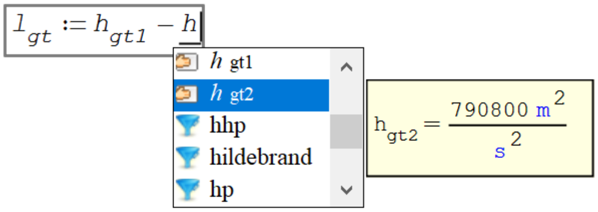
Fig. 4. Substitution of numerical values in a formula (Mathcad Prime)

But the *explicit* operator is almost never used nowadays for a number of reasons. First, it has difficulties when working with dimensional quantities. Secondly, Mathcad's numerical and symbolic mathematics are mixed here, which makes it difficult to properly format numbers. Thirdly, in Mathcad Prime, unlike the good old Mathcad 15, you cannot hide the explicit keyword.

But the main reason for not duplicating formulas is that the substitution of numerical values into formulas (Fig. 4) was necessary only to conduct additional verification of the correctness of manual calculations or those made using a slide rule or calculator. Currently, calculations are carried out on a computer, which eliminates arithmetic errors. Errors can be in the values of individual variables included in the calculation formula. But this error cannot be revealed by the substitution described above. However, some design organizations and universities are still guided by outdated unspoken standards and require employees and students to duplicate formulas with substituted variable values, not content with the method shown in Fig. 1 when the values of the formula variables are displayed below the formula, following the word "*where*".

In Soviet research institutes and design bureaus there were entire departments where girls sat and checked the correctness of arithmetic calculations made by employees from other departments on adding machines and other non-electronic devices. For them, it was necessary to duplicate the formulas, substituting the numerical values of the variables into them (Fig. 3 and 4).

Let us mention in passing that in the SMath environment, when a variable is entered into the calculation formula, it is not only duplicated in the drop-down window, but "digitized" showing its numerical value - see fig. 5. In the future, it may additionally describe what physical quantity is present - the specific mass enthalpy of the gas, and not the internal energy or something else with the same combination of units of measurement.



$$l_{gt} := h_{gt1} - h_{gt2} = 6.922 \cdot 10^{5}\ \mathrm{Gy}$$

Fig. 5. Tooltip when entering a variable in a formula

Figure 5 highlights another problem that the AI system must solve. In the Mathcad environment, the specific mass energy is printed out with the compound unit m^2/s^2 reduced as much as possible. This is what is shown in the yellow box in Fig. 5. But the SMath environment makes a mistake here in the other direction - it prints this physical quantity with the unit of the absorbed dose of ionizing radiation Gy (Gray), which has to be manually changed to the more familiar compound unit kJ / kg (see Fig. 1). In passing, another question arises. And why can't this correct unit of specific mass enthalpy be reduced by J / g (joules per gram)!? But habit is second nature: here we stubbornly write and pronounce kilojoule per kilogram, without removing the notorious kilo. The kilogram unit of mass is a rather strange unit. It is the only base in SI that has a kilo multiplier. Because of this, the unit of mass μg can be interpreted both as a microgram (μ g) and as a millikilogram (m kg), that is, a gram.

Figure 6 shows a calculation in the SMath environment using the author's application WaterSteamPro (www.wsp.ru), of the viscosity of water under normal conditions. By default, the answer is displayed with a rather strange unit of measurement from the point of view of physics: pascal multiplied by a second - see the first operator in fig. 6, which is nevertheless recommended in the SI as the basic unit of viscosity [5]. The unit is strange because it loses the physical meaning of viscosity - the force of viscous friction. But the main thing here is that Blaise Pascal (1623-1662) did not work with viscosity. Isaac Newton (1642-1727) dealt with it. There is even such a thing as Newtonian fluid..

$$\mathrm{wspDYNVISPT}(1\ \mathrm{atm};\ 20\ {}^{\circ}\mathrm{C}) = 0.001002\ \mathrm{s\ Pa}$$

$$\mathrm{wspDYNVISPT}(1\ \mathrm{atm};\ 20\ {}^{\circ}\mathrm{C}) = 1.002\ \frac{\mathrm{N\ mm}}{\frac{\mathrm{m}}{\mathrm{s}}\ \mathrm{m}^{2}}$$

Fig. 6. Calculation of the viscosity of water in the SMath environment

The second operation in Fig. 6 shows a non-standard (“three-story”), but correct from the point of view of physics, viscosity unit. If two plates with an area of 1 m^2 each are placed at a distance of 1 mm from each other, and water is poured into the gap under normal conditions and the plates are moved relative to each other at a speed of 1 m / s, then this will require a force equal to approximately one newton. Approximately as viscosity is measured experimentally. An AI system that supports physical quantities in calculations must return the physical meaning of units of measure by eliminating far-fetched unnatural reductions and substitutions.

Conclusion on point 2. An AI system that supports physical units in calculations should divide the calculation variables into those that have an independent physical meaning, and those whose physical meaning is manifested only when working with the differences of these quantities. In addition, some composite and simplified units of measurement must be returned to their physical meaning..

3. Working with decibels and other "logarithmic" units of measurement

Units of measurement are usually tied to numerical values through multiplication. But there are some units for which the connection with the number is carried out in a more complex way; decibels for example [6].

Bel (B, B) is the decimal logarithm of the ratio of two quantities with the same dimension. If you use the natural logarithm instead of the decimal one, then the unit of measurement is called a non-pen (Np, Np). A decibel (dB, dB) is one tenth of a bel.

SMath has decibels and dekabels built in [2] – see fig. 7, but they have nothing to do with the essence of these specific units of measurement. A decibel simply stores one, and a dekabel is a hundred times the decibel. And this decibel cannot be added to a meter, for example.

[2] Decabels are practically not used. This is also evidenced by the fact that the spell-checker of the Word text editor, in the environment of which this text of the article was typed, underlined this word with a red wavy line..

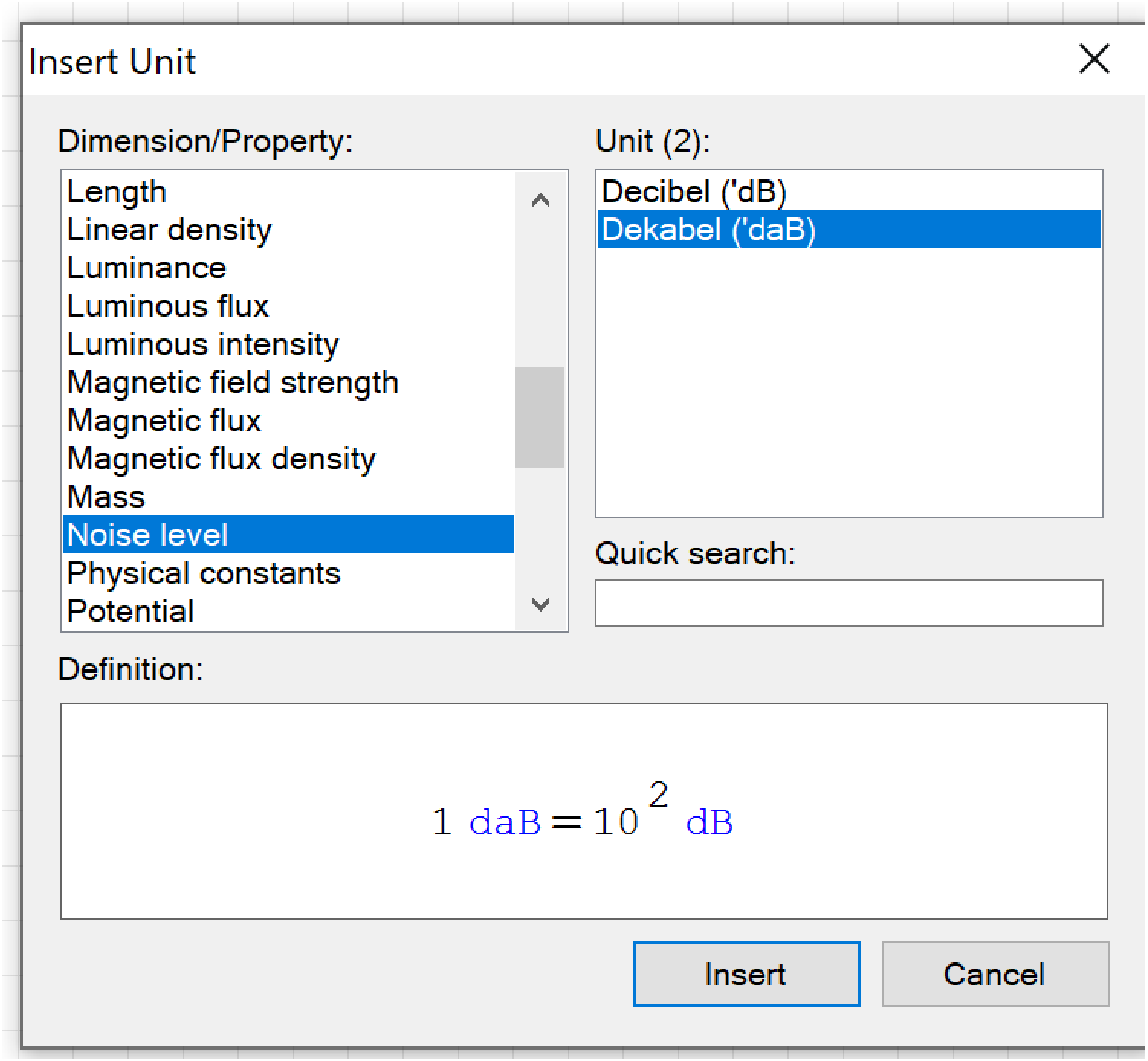


Fig. 7. Entering deci- and dekabels in the SMath environment

Decibels and dekabels in this form play a purely decorative role - the role of some comments. For them to really work, it is necessary to take into account the fact that the logarithm in decibel operates with a fraction, the denominator of which is taken as a certain base (base), from which the calculation is carried out. It would be possible to simply work with a fraction, and not with its logarithm, but then the range of change in the values of this fraction would be very large, which was very inconvenient for manual calculations in the pre-calculator and, especially, in the pre-computer era. So non-physical entities were introduced into the calculations in order to significantly narrow this spread through the use of logarithms[3]. Nowadays, computer tools for solving problems are not afraid of such spreads of values, and decibels can be completely abandoned, leaving them only to

[3] There is another not so obvious reason, indirectly related to metrology. The nature of the reflection in the sense organs of man and animals of changes in the course of many physical and biological processes is proportional to the logarithm of the intensity of the stimulus (see the Weber-Fechner law). This feature makes the use of logarithmic scales, logarithmic quantities and their units quite natural. For example, one of these scales is the musical equal-tempered frequency scale.

display the results of calculations for those who are used to them, for whom they "entered the blood and flesh" of the calculation practice.
A concrete example of working with decibels.
Suppose we want to express the power of a power plant in decibels.
Here is how (Fig. 8) in the Mathcad 15 environment such a calculation may look with the use of tools for separating variable and function names into styles using different font colors (black, green, blue and white - invisible) and a prefix operator.
If one watt is taken as the base, then the power of the largest Russian thermal power plant, Surgutskaya GRES-2, would be 96.812 decibels.

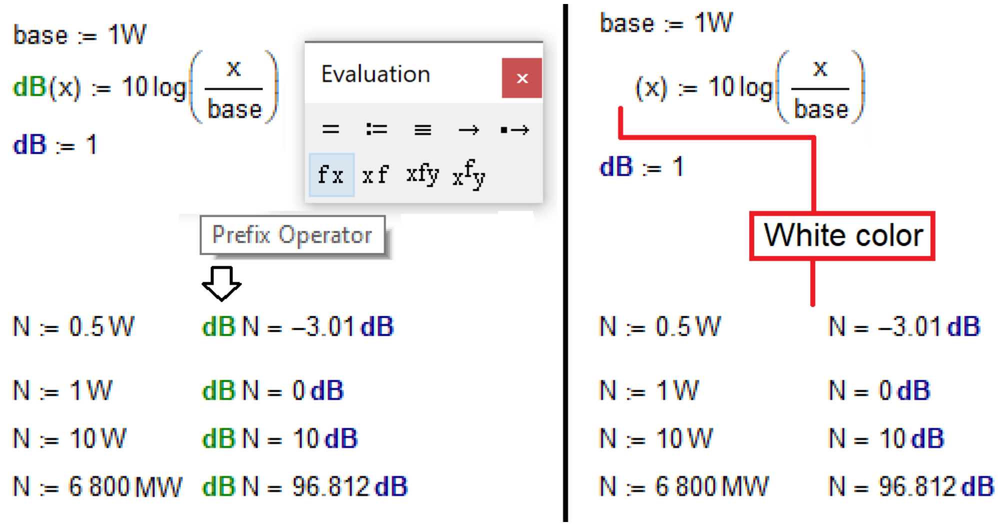


Fig. 8. Calculation of power in decibels

Based on Fig. 8, which is divided into two parts by a vertical bar, first, the value of the variable base is entered, and then a function called dB is formed on its basis. On the left side of the calculation, this identifier is colored green, and on the right side it is white, which makes it invisible against the white background of the display screen. Additionally, a variable with the same name dB is introduced, but this is a completely different variable that simply stores a numerical unit (number 1).
After entering the power value in the variable N with the corresponding "normal" power units (watt, kilowatt, megawatt, etc.), it is converted to decibels through the dB prefix function call. The answer is given without units of measurement, therefore, for better understanding, it would be necessary to attribute the unit constant dB to it.
After replacing the green color of the variable name with white and hiding the first three service statements in the collapsed area, the calculation view becomes quite natural - see the right side of Fig. 8. The power value is entered into the variable N, which is immediately printed out in decibels.
In addition to the prefix operator with one operand, you can use the infix operator with two operands, the second of which is the base.
The inverse problem (power is given in decibels, but you need to calculate it in watts) is easier to solve - see fig. 9. It is enough to enter into the calculation a user function named dB, which is also called as a prefix operator, but without changing the color to white.

$$dB(x) := base \cdot 10^{\frac{x}{10}}$$

$$N := 0\ dB = 1\ W$$

$$N := 1\ dB = 1.259\ W$$

$$N := 10\ dB = 10\ W$$

$$N := 100\ dB = 10000\ MW$$

Fig. 9. Calculation of power in watts given in decibels

In fig. 7, below the decibel input dialog box, the sum of two embedded decibels is shown equal to two decibels. But this, no matter how strange it may seem, is not at all the case - see fig. 10. The sum of two decibels with a base equal to 1 watt is (approximately) 2.518 watts or 4.01 of the same decibels. In the left half of Fig. 10 you can see the "green" function named dB (see fig. 8 where it is created), in which the color was changed to white in the right half of the figure.

$N_2 := 1\ dB + 1\ dB$	$N_2 := 1\ dB + 1\ dB$
$N_2 = 2.518\ W \quad dB\ N_2 = 4.01\ dB$	$N_2 = 2.518\ W \quad N_2 = 4.01\ dB$

Fig. 10. The sum of two decibels

In short, as people say, you can’t figure it out without a bottle. We will say a little more intelligently: without AI, it is very difficult to understand computer calculations involving decibels. Working with decibels in the SMath environment was discussed on the forum https://en.smath.com/forum/yaf_postst23421_dB.aspx.

Decibels are primarily associated with the power of sound. But decibels have firmly entered the calculation practice of radio engineers. There are many empirical, more precisely, pseudo-empirical formulas [7], where decibels are present. These formulas do not fit in with modern programs that operate on physical quantities. AI can remove this inconsistency.

The decimal logarithm is also present in parameters such as the pH value of water and aqueous solutions [4]. If you google, you can find the following information about this value: pH is the negative decimal logarithm of the activity of hydrogen cations (H +), expressed in moles per liter. And none of the people are embarrassed by the fact that the logarithm of the dimensional value is calculated. There is no unity in the definition of the ion activity itself. Some consider this value to be dimensional, some consider it to be dimensionless. All this is “confused” only by the computer on which the calculations are carried out - see fig. 11 with the corresponding error message. If you make the necessary division by a certain base and thereby deprive the argument of the logarithm of dimension, then the calculation will be done without error. The pH value here will differ from white only in sign.

[4] Once upon a time there was an obsessive advertisement for a cream with pH = 5.5 on TV. Such an acid indicator has human skin.

$$[H^+] := 0.57\,\frac{mmol}{dm^3} = 0.57\,\frac{mol}{m^3}$$

$$pH := -\log([H^+]) = ■■$$

This value has units: Substance · Length^-3,
but must have units: Unitless.

$$pH := -\log\left(\frac{[H^+]}{1\,\frac{mol}{dm^3}}\right) = 3.244$$

$$dm^3 = 1\,L$$

Fig. 11. pH value calculation

By the way, about the moles appearing in the calculation in Fig. 11. They are different, given that they set both molar and normal concentrations. Previously, the gram-equivalent unit was used for normal concentration instead of the mole. Then they banned the use of gram equivalents - only moths should be everywhere. If we see somewhere that the hardness of water is equal to two millimoles per liter, then we must understand that we are talking about normal, and not about molar concentration - about the sum of not the calcium and magnesium cations themselves in water, but about the sum of the charges of these cations , which are twice as many. For hydrogen cations, written in the calculation in Fig. 11, moles are the same in both normality and molarity. But if we are dealing with two or more charged ions, then the moles there will differ significantly. This nuance should also not be left without attention of the AI system, which is discussed in the article. Figure 11 touched on the problem of variable and function names in calculations. Mathcad 15 is the most advanced in this regard. In its environment, you can use the keyboard shortcut Shift + Ctrl + j to enter square brackets into calculations, inside which you can write complex variable names using arithmetic and other operations. For example, raising the variable H to a plus power and getting the name H+. This useful feature should be in other physics and mathematics packages. Below fig. 11 Mathcad 15 printed 1 cubic decimeters as one liter. Here lies the error from the point of view of metrology: a liter is a unit of capacity, not volume. Such nuances can also be taken into account by means of AI.

Astronomers, like chemists, also have a certain decibel, but not logarithmic, but linear. The angular diameters of celestial bodies are measured in arc minutes and seconds, instead of the radians set in the geometry[5]. So the maximum angular diameter of the Moon is 33 minutes and 5 seconds, which, translated into radians, will give approximately 0.00962 poorly perceived (readable) radians.

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[5] There is a metrological continuation of the old joke about a balloon and mathematics. The balloon broke out of the clouds. The flying people saw a man on the ground and shouted: “Where are we?”. “You are in a balloon basket!” was the answer. It was given by a mathematician. Only from a mathematician can you hear an absolutely accurate and absolutely useless answer. The author's continuation of this anecdote is as follows. Those flying in a balloon shout down: “You misunderstood us - we want to know our location, and our navigator has run out of battery!”. The mathematician looked at his smartphone and shouted: “Zero point five hundred and ninety-six thousandths radians

There were attempts to "decimalize" angular values by introducing a unit of degrees, which in a right angle is exactly one hundred, not ninety. But this was not successful. The same story was true of the measurement of time. Rather so. There are miles, micros and other "small seconds", but no kilos, megas and other seconds instead of minutes, hours, etc. In the Mathcad environment, by the way, there are tools and conversions. There, length can be expressed in English feet and inches, time in hours, minutes and seconds, and angle in degrees, minutes and seconds. This is very convenient for those who are used to such units.
Here we can also mention the defaults in metrology. If, for example, we learn in Turgenev's story "Mumu" that Gerasim's height was 12 inches, then the AI should suggest that two arshins should be added to the inches, which every adult has.

Conclusion on point 3. An AI system that supports physical units in calculations must be able to work correctly with decibels.

4. Working with conditionally dimensionless quantities

Figure 11 shows the calculation of the pH value of water. Is it possible to add this dimensionless quantity to another dimensionless quantity - with a radian, for example. Can you add a radian to a steradian? Both quantities are considered dimensionless. It is impossible to do this in the SMath environment - see fig. 12. In earlier versions of Mathcad, this could not be done either, but then (later versions of Mathcad and Mathcad Prime) this rather reasonable restriction was removed. But a radian can still be added to a percentage...

1 rad + 1 sr = ■ ■

Units?

1 rad + 1 % = 1.01

1 rad + 1 % = 1.01 rad

1 rad + 1 % = 101 %

Fig. 12. Working with conditionally dimensionless quantities

But radians and steradians are not completely dimensionless quantities. A radian is the ratio of length to length, and a steradian is the ratio of area to area. Therefore, the addition of a radian to a percentage should also be blocked. Yes, and the percentage cannot be considered a dimensionless quantity, if we take into account that this is the ratio of two identical physical quantities. If we calculate the logarithm of such a fraction, then we get the white, which was discussed above.

In the SMath dialog box for entering units of measurement, there is a group named Dimensionless (see Fig. 13, where the radian and other angular flat units occur. But for some reason the solid angle (steradian) is in a different group. However, it cannot be added to the radian.

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north and zero point three hundred and sixty-four thousandths radians east!” Only mathematicians measure angles in absolutely correct, but absolutely useless radians, and not in degrees-minutes-seconds.

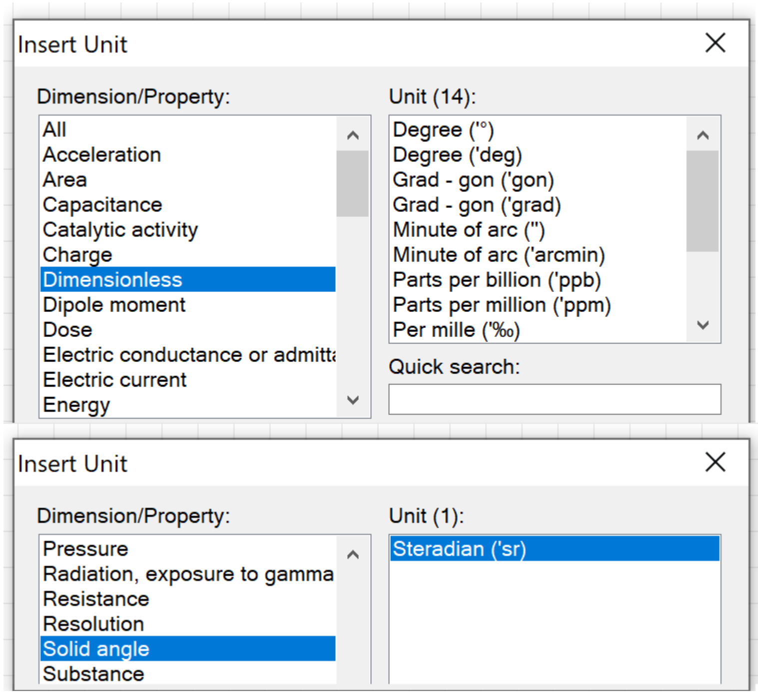

Fig. 13. Groups of SMath units

The values returned by the sine of the angle and other trigonometric functions cannot be considered dimensionless either, because the legs and hypotenuse of a right triangle have the dimension of length (distance), which in principle cannot be reduced in fractions. The question of whether it is possible to add an angle and its sine, for example, remains open.

Conclusion on point 4. An AI system that supports physical units in calculations must “deal” with the concept of “dimensionless physical quantity”.

5. Work with the "correct" unit of temperature and with all physical quantities, where it is included

As you know, in the international system of measurements (SI) there are “exactly” seven basic units - kilogram (mass), meter (distance), second (time), ampere (electric current), mole (amount of substance), candela (luminous intensity) and kelvin (temperature). But physicists say that only three units (kg-m-s) are enough for a metric description of the world. The remaining four units (ampere, mole, candela and kelvin) are "from the evil one", or rather, from the principle that "truth is good, but happiness is better."
An ampere, with some reservations (a different record of Coulomb's law), can be expressed in terms of a meter to the power of one and a half, multiplied by the square root of a kilogram and divided by a second squared. In order not to deal with such a complex "three-story" unit of current strength, the unit ampere was introduced into metrological use (recall the pascal multiplied by a second in Fig. 6). When the SI was created in Europe, the "founding fathers" of this measurement system were under the euphoria that all the world's problems would be solved once and for all with the help of electricity. How can you do without a basic electrical unit - without an ampere!? And why didn’t they insert a volt or an ohm instead of an ampere into the “magnificent seven SI”? But because Alessandro Volta (1745-1827) was an Italian, Georg Ohm (1789-1854) was a German, and André-Marie Ampère (1775-1836) was a native Frenchman! France, with its Great French Revolution, stood at the origins of the kilogram and meter. But then the British were offended and insisted that

William Thomson (1824-1907) not only be awarded the title of lord, but also a nominal unit of measurement. That's what the Kelvins came up with. And now it's embarrassing to cancel and admit that they twisted against the truth. Physicists understand this well, using units of energy (eV - electron volt, for example) for their calculations when fixing the temperature.
Moles (see above) are nothing more than dimensionless things. If the power of light was introduced into calculations as the basic SI unit, then it would be necessary to come up with a basic unit of sound power, smell power etc. But why did the kelvin become the basic SI unit? Can this unit of temperature be reduced to the Gaussian triad "mass-distance-time"? Can!

Task. Oxygen is stored in a 40 liter cylinder at an overpressure of 150 bar. The barometer shows atmospheric pressure of 745 mm Hg. Cylinder and gas temperature 10℃ (stationary mode). Determine the mass of oxygen in the balloon, based on the equation of an ideal gas, connecting the basic trinity of thermodynamics: pressure p, temperature T and specific molar volume - the volume occupied by a mole of gas with an Avogadro number of atoms or molecules. I immediately remember the school 22.4 liters - the volume of an ideal gas under normal conditions. The metrologist will correct us here - not a liter, but a cubic decimeter. A liter is a unit of capacity, not volume.

Figure 14 shows how the initial data of the oxygen cylinder problem are entered with the conversion of dimensions to SI base units. Then, through simple calculations, the solution to the problem is found - 8.2 kilograms of oxygen are stored in the cylinder. The weight of the cylinder will decrease by approximately this value if oxygen is released from it (by the way, the degree of filling of a propane-butane liquefied gas cylinder is often controlled by placing the cylinder on a scale).

$$V := 40\ \mathrm{L} = 0.04\ \mathrm{m}^3$$

$$M_{O2} := 32\ \frac{\mathrm{g}}{\mathrm{mol}} = 0.032\ \frac{\mathrm{kg}}{\mathrm{mol}}$$

$$p_a := 745\ \mathrm{mmHg} = 99325.1786\ \mathrm{Pa}$$

$$p_{изб} := 150\ \mathrm{bar} = 1.5 \cdot 10^7\ \mathrm{Pa}$$

$$p := p_a + p_{изб} = 1.5099 \cdot 10^7\ \mathrm{Pa}$$

$$T := 10\ \mathrm{^\circ C} = 2354.2428\ \frac{\mathrm{J}}{\mathrm{mol}}$$

$$\boxed{p \cdot v = T}$$

$$v := \frac{T}{p} = 0.0001559\ \frac{\mathrm{m}^3}{\mathrm{mol}}$$

$$M := \frac{V}{v} \cdot M_{O2} = 8.2095\ \mathrm{kg}$$

Fig. 14. Determination of the mass of oxygen in the cylinder

In the last sentence, an inaccuracy was deliberately made: weight is measured in units of force, and not units of mass - newtons, not kilograms. Weight (gravity) and mass are often confused. These two physical quantities are related by Newton's second law.

Imagine that you open a physics textbook and see a formula like: m a = k F with an explanation that this is a mathematical notation of Newton's second law, where m is mass (mass), a is acceleration (acceleration), F is force (force) , and k is the universal force constant. Of course, you will be surprised and say that there should not be any constant k in this formula. But you will be wrong in the sense that the constant k serves to convert the force expressed in kilogram-force into newtons, and the acceleration of free fall is hidden in the constant k. And they will explain that people have long been accustomed to expressing force in kilograms-force, and not in some incomprehensible Newtons. That is why this formula contains the value k, which is called the universal force constant (a force constant). Force can be expressed in other common units - in dynes, in pounds-force, and so on. (see their full list, for example, here https://www.calc.ru/Sila/?ysclid=lbxb3a3osr936832601). But all this must first be converted into kilograms-forces, and only then insert the resulting value into the formula for Newton's second law m a = k F.

But if we open a textbook on classical thermodynamics - one of the sections of the same physics, then we will see in reality a similar formula p v = R T “burdened” with the constant R with an explanation that p is pressure (pressure, pascals), v is the specific molar volume (volume, cubic meters divided by moles), T is temperature (temperature, kelvins), and R is the universal gas constant (joules divided by moles and kelvins), which is used to convert kilograms-force, sorry, degrees Kelvin, more sorry, kelvins in ... the correct units of temperature.

So, in the problem of the mass of oxygen in a balloon, the correct ideal gas equation $p\ v = T$ was used, not burdened by the conversion coefficient R. The entered temperature of 10°C is stored in the computer’s memory not in kelvins, but in joules divided by a mole. The remaining initial values are stored in a computer with the usual SI base units: not in liters, but in cubic meters, not in grams per mole (the molar mass of diatomic oxygen), but in kilograms per mole, not in bars or mm of mercury, but in pascals . But the temperature, we emphasize again, is stored in units of energy divided by units of the amount of matter.

The fact that the temperature expressed in kelvins and other temperature degrees is incorrect has long been known. Here is what you can read in the fifth volume of the famous course of theoretical physics by Landau and Lifshitz [8] *“... Temperature has the dimension of energy and therefore can be measured in units of energy, for example, in ergs. However, the erg turns out to be ... too large a value, and in practice it is customary to measure temperature in special units called degrees Kelvin or simply degrees. The conversion factor between ergs and degrees is called the Boltzmann constant k = 1.38·10-16 erg/deg. We will agree further in all formulas to mean temperature measured in energy units. For the transition in numerical calculations to a temperature measured in degrees, it is enough to simply replace T by kT. The constant use of the multiplier k, the only purpose of which is to remind us of the conventional units of temperature measurement, would only clutter up the formulas* ”.

Figure 15 shows how, in the SMath environment, the entered temperature (twenty degrees Celsius [6]) is converted not to ergs, but to joules using the built-in constant - the Boltzmann constant k. The resulting numerical value is too small. It is very difficult to work with it in manual calculations. That is why normalizing coefficients (the universal gas constant and the Boltzmann constant) are introduced, which allow us to switch to the “normal” temperature scale with nominal degrees. The computer, on the other hand, quite calmly operates with any values, which allows us to return the temperature to its lawful unit of measurement [9]. Here the story, as with decibels and pH value, is repeated.

[6] Yes, that's right, not "ten degrees Celsius", which can be interpreted as ten kelvins.

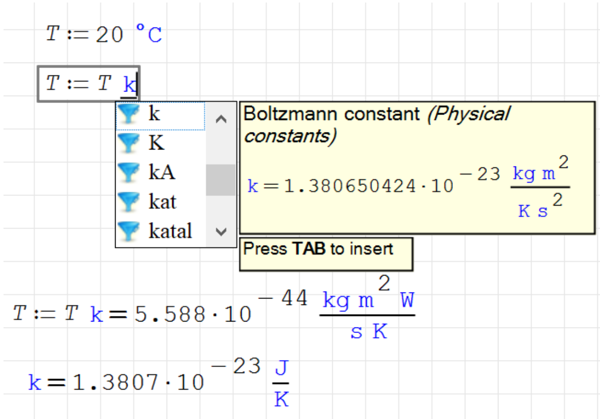

Fig. 15. Boltzmann constant in SMath

Historically, the empirical concept of temperature first appeared with different nominal degrees and scales (Fahrenheit - 1724, Reaumur - 1730, Celsius - 1742, etc.), but only much later, almost a century later (1834 - 1874: Maxwell, Boltzmann, Clapeyron, Clausius, Mendeleev, etc.) a theoretical equation of state of an ideal gas was derived with the concept of temperature, which had to be adjusted to "degrees" by introducing the concept of "universal gas constant". Here lies the mystery of why temperature has become not just a separate physical quantity, but the main physical quantity in the SI. And it should be a composite value, which is what we are trying to show in this section of the article. This is indirectly evidenced by the fact that until 1968 the kelvin was officially called the degree of Kelvin. And degrees in those days were everywhere expelled from metrology [10] and transferred to the category of auxiliary quantities. Recall angular degrees, degrees of hardness, degrees of Engler (liquid viscosity), degrees of water hardness, alcohol degrees, etc. Yes, the Kelvin degree was renamed to Kelvin. But this is similar to how the "metrological house" did not carry out a major cleaning, did not remember that temperature is inherently a special type of energy, but simply ... swept the garbage under the carpet - they introduced the universal gas constant. There was not enough political will for a number of reasons to completely abandon temperature degrees. By the way, the degree of Rankine (an overseas analogue of the degree of Kelvin, sorry, Kelvin) has remained the degree of Rankine (°Ra): there are no rankins (temperature units on an absolute scale) in metrology and are not expected.

The aforementioned theoretical physics course was written at a time when there were no computer tools for working with physical quantities and calculations had to be done manually, on arithmometers, on a slide rule... Then electronic calculators, "non-physical" programming languages and spreadsheets appeared. In our time, we repeat, we can return to the origins, to the fact that from the standpoint of metrology, temperature is not a separate physical quantity, but energy divided by the amount of substance with a conversion coefficient called the universal gas constant (or Boltzmann constant - see Fig. . 15). The unit kelvin is then converted into the category of an auxiliary unit of temperature.

Figure 16 shows the units in which some physical quantities are stored, in the units of which there are kelvins. In this case, the Boltzmann constant is numerically equal to the reciprocal of the Avogadro number, and the entropy finally becomes dimensionless, which brings the meaning of this quantity closer between statistical physics and classical thermodynamics.

Thermal conductivity	$\frac{W\ m}{m^2\ \frac{J}{mol}} = 1\ \frac{mol}{m\ s}$
Thermal resistance	$\frac{\frac{J}{mol}}{W} = 1\ \frac{s}{mol}$
Specific mass heat capacity	$\frac{J}{kg\ \frac{J}{mol}} = 1\ \frac{mol}{kg}$
Specific molar heat capacity	$\frac{J}{mol\ \frac{J}{mol}} = 1$
Specific molar entropy	$\frac{J}{mol\ \frac{J}{mol}} = 1$

Fig. 16. True units of some physical quantities

But such reductions confuse many. Recall the reduction of kilojoule per kilogram to square meters per second squared in Fig. 5. This is one of the reasons why they do not want to abandon the kelvin as the basic unit of the SI.

But the AI system will be able to help the user to print these values with familiar units.

The dispute about degrees of temperature in a unit of thermal conductivity is resolved radically - there are no temperature units there, but only moles, meters and seconds - see fig. 17.

$$\lambda := 54.47\ \frac{W\ cm}{m^2\ K} = 6.5508\ \frac{mol\ cm}{m^2\ s}$$

Fig. 17. Basic unit of thermal conductivity

By the way, in the unit of thermal diffusivity (thermal conductivity divided by the specific mass isobaric heat capacity and density) there are no temperature units, but only square meters divided by seconds. Temperature has moved from a unit of physical quantity to its name. The introduction of the concept and thermal diffusivity was an attempt to get around the inconsistencies associated with the empirical approach to temperature and with the complex history of this physical quantity.

The rejection,l in computer calculations, of the unit of temperature as one of the seven basic units of the SI may not occur immediately, but will occur with a certain transitional period, which has a beginning, but may not have an end. Figure 18 shows the SMath package setup window, where you can tick the last line and switch from the four-term (pv=RT) to the three-term (pv=T) formula of the ideal gas equation. After that, the temperature entered in any degrees and on any scales will first be converted to kelvins, and then, by multiplying by the universal gas constant, converted into a numerical value with a composite unit of joule divided by mole. In this numerical form, the temperature will be stored in the computer's memory..

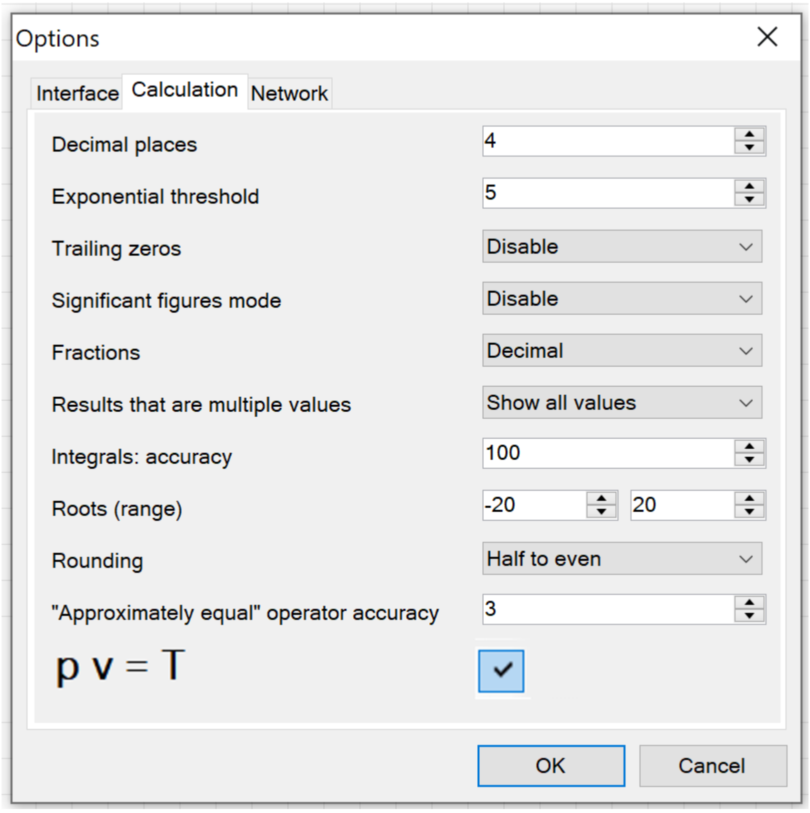

Fig. 18. Switch in the SMath environment to the correct temperature units (to the correct ideal gas equation)

Figure 19 shows a dialog box for entering temperature units, in which (after setting the appropriate checkbox - see Figure 18) the correct temperature unit, joule divided by mole, will appear in the first place.

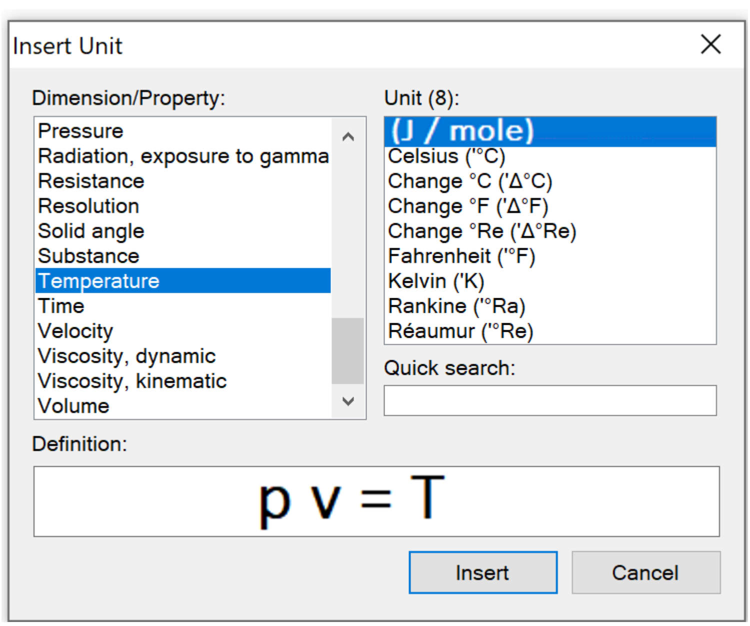

Fig. 19. Dialog box for entering temperature units

The question is, why do all this with temperature!? And then, to finally put some sort of order in the system of units of measurement. Remove, for example, such inconsistency when physicists measure temperature in electron volts, and all other “normal people” in degrees Kelvin, Celsius, Fahrenheit, Rankine, Réaumur, etc. At the same time, no one is going to cancel, let alone ban the usual scales and degrees of temperature . It's like with angular units - everything needs to be counted in radians, but the answer should be displayed in degrees, minutes, seconds. The principle “The truth is good, but happiness is better!” good for everyday life and politics with its double standards, but not for science.

And one more important note on temperature. There are two international temperature scales - 1968 and 1990. The author's settlement site shown in fig. 20 allows you to recalculate according to these scales.

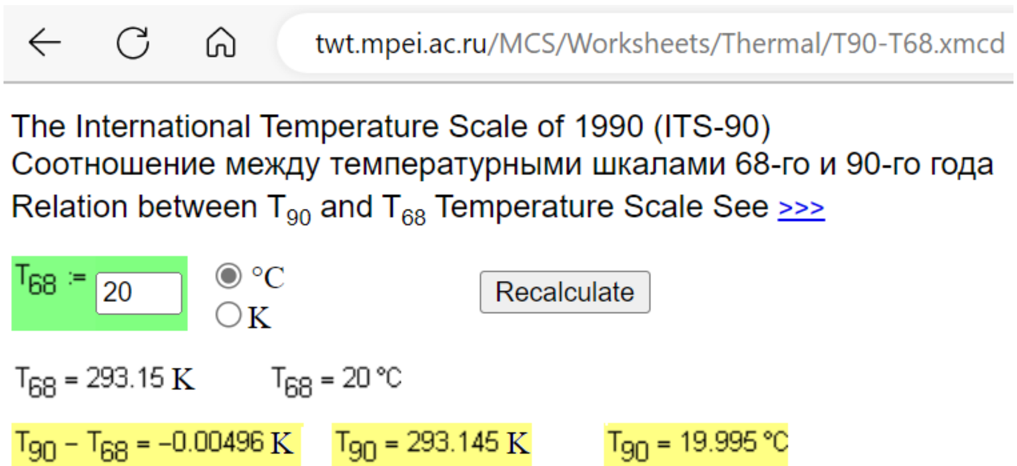

Fig. 20. Interactive web application for calculating the temperature difference according to the international scales of 1968 and 1990

Figure 21 shows a graph of the temperature difference according to the international scales of 1968 and 1990 with eight fixed points. It is placed on the site described above, where the corresponding calculation formulas are also shown..

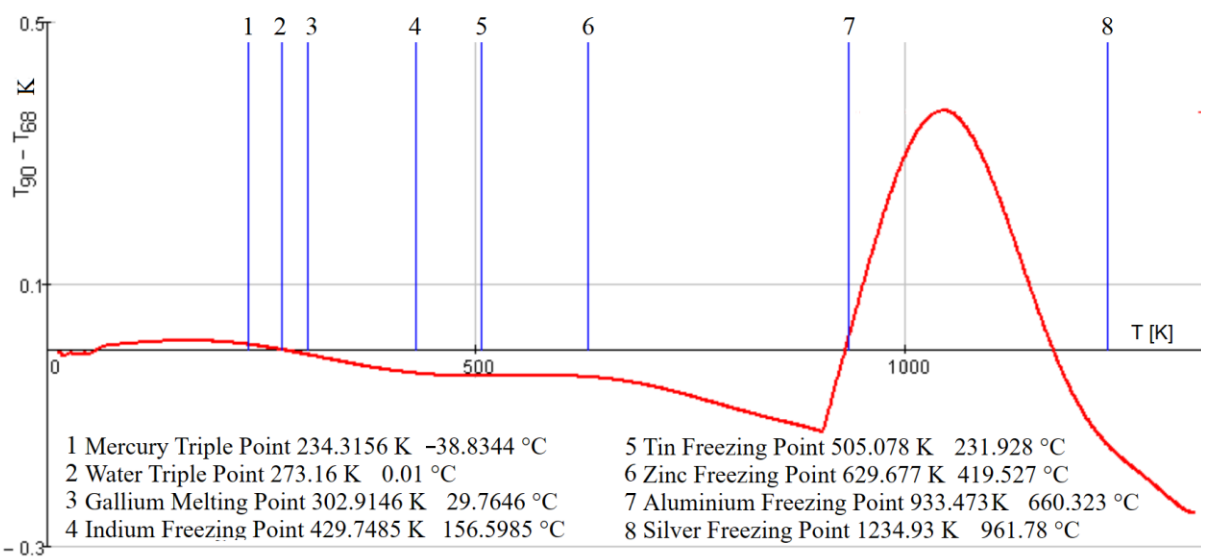

Fig. 21. Graphical display of the temperature difference according to the international scales of 1968 and 1990

In principle, when entering the temperature with a call to the dialog box shown in fig. 19, it is necessary to clarify which international temperature scale is meant. This is another concern of the AI system, which is discussed in this article.

Conclusion on point 5. Modern computer calculation programs make it possible to finally complete the long historical process of transition to the correct temperature units. At the same time, it remains possible to work with the usual temperature degrees and scales when entering and displaying temperature values and other quantities containing temperature units..

6. Working with technical and economic quantities

The international SI system needs to be changed in this direction as well. In it, it is not only necessary to reduce the number of basic values (see above), but to add new ones - to include values for the cost and amount of information, for example. Although the amount of information can be measured in moles, and the speed of its transmission with catals - in moles divided by a second. Catal is a rarely used unit of catalytic activity, the rate of chemical reactions.

Figure 22 shows the dialog boxes of the Mathcad Prime and SMath packages with units of cost and information. But there is no package in the world in its basic state (without loading add-ons, plugins) that stores both of these values.

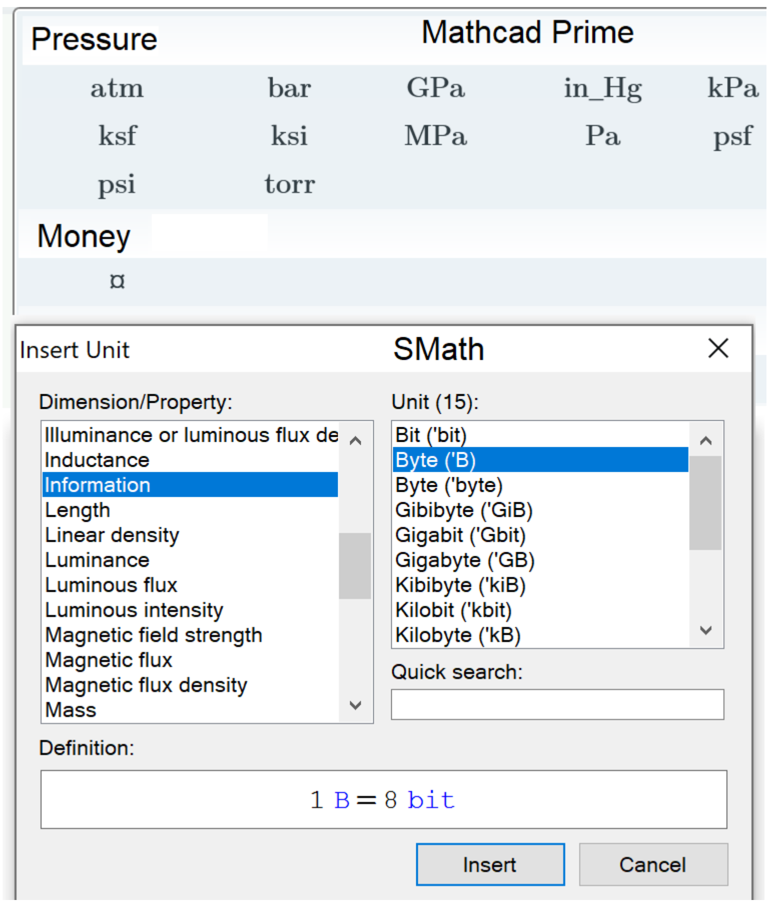

Fig. 22. Dialog boxes for entering cost units and information

However, through a special add-on (plug-in) it is possible to link the exchange rates of world currencies to the euro to the SMath environment (see Fig. 23) and automatically adjust this link every exchange business day.

$$\mathrm{SetCurrencyUnits}(1)=\begin{bmatrix}\text{"number of available currencies: 31"}\\ \text{"invalid base currency"}\\ \text{"base currency: EUR"}\\ \text{"reference rates date: 2023-04-26"}\\ \text{"XML database date: Wed, 26 Apr 2023 13:55:12 GMT"}\end{bmatrix}$$

$$RUB:=\frac{USD}{81.49}$$

Fig. 23. Input operator in the exchange rate SMath environment

Such a connection of the exchange rate allows, for example, quite simply and beautifully to solve the following problem. It is necessary to choose a carrier of information from two possibles. The first one has a capacity of 128 gigabytes and costs 2580 Russian rubles (see the operator in the lower left corner of Fig. 23 - the ruble exchange rate is taken from the website of the Central Bank of Russia, the remaining rates of thirty currencies are loaded automatically with a base of one euro). The second storage medium can store up to one terabyte of information, but it costs more - $ 300. What storage medium is worth buying, other things being equal? Answer: you need to buy the first one, from which 49.61 megabytes are purchased for one ruble, and not 40.9, like the second - see the boolean operator "greater than" that returned one (true), not zero (false).

$$HD_1:=128\ GB=1.28\cdot 10^{11}\ B$$

$$Price_1:=2580\ RUB=31.66\ USD$$

$$HD_2:=1\ TB=1\cdot 10^{12}\ B$$

$$Price_2:=300\ USD=24450\ RUB$$

$$\frac{HD_1}{Price_1}=49.61\ \frac{MB}{RUB}\qquad \frac{HD_1}{Price_1}=4.043\ \frac{GB}{USD}$$

$$\frac{HD_2}{Price_2}=40.9\ \frac{MB}{RUB}\qquad \frac{HD_2}{Price_2}=3.333\ \frac{GB}{USD}$$

$$2^{30}=1073741824\ \text{Mebibyte}$$

$$2^{40}=1099511627776\ \text{Teribyte}$$

$$\frac{HD_1}{Price_1}>\frac{HD_2}{Price_2}=1$$

Fig. 24. Feasibility study of the quality of two storage media

Note that megabytes and terabytes, to the surprise of specialists in working with information, have recently been deciphered, so to speak. The usual twos to the power of 10, 20, 30, etc. instead they gave other names - see the lower left corner in fig. 24.

Figure 25 shows the button bar of the SMath package with world currency symbols that can be inserted into calculations instead of the abbreviations RUB and USD used in fig. 24.

Fig. 25. Symbols of different currencies in the SMath environment

Conclusion on point 6. Mathematical packages can be called not only physical and mathematical, but also technical and economic packages with full support for units (values) of information and currency.

7. Fixed support of calculations

Figure 26 shows the dialog boxes for entering physical constants (constant) into calculations - SMath on the left, Mathcad Prime on the right.

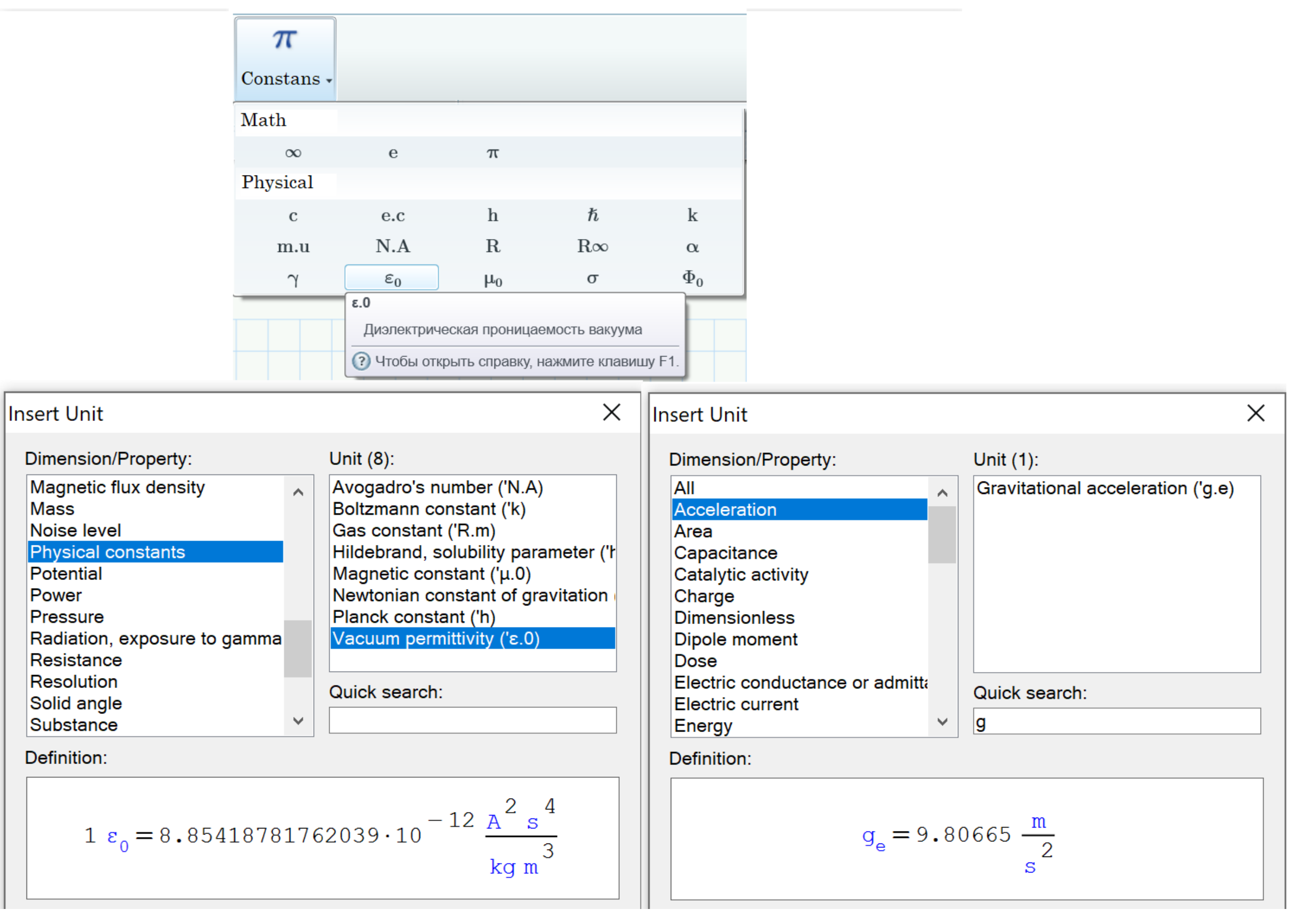

Fig. 26. Panels with buttons for entering constants

The middle of Fig. 26 shows a dialog box for entering the value of the free fall acceleration into the calculation. It is considered not a constant, but a unit of acceleration. This is not a constant because it depends at least on the height above sea level and the latitude of the area. But other constants can also change as a result of clarifying their values and subsequent approval by the relevant authorities (the leadership of the relevant scientific communities).
By the way, if you check the box in the dialog box in Fig. 18 (pass from the formula pv=RT to the formula pv=T), then in the dialog boxes on the left and right in fig. 26 the universal gas constant disappears.

Conclusion on point 7. The AI system can be useful when working with built-in constants.

8. Possibility of solving mathematical problems with physical quantities.

The most advanced package in the field of using physical quantities is the Mathcad Prime package. In it alone, for example, you can numerically solve differential, integral and algebraic equations (and their combinations) with units of measurement. Which is very convenient and useful in solving problems of mathematical physics. But this package also has limitations in this regard. So in fig. 27 shows that when taking the rank of the dimensional matrix, an error message is generated, which itself contains an error, or rather, inaccurate information. The message should be something like this: "Matrix elements must be dimensionless values."

$$M=\begin{bmatrix}\left(2.163\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -8.139\cdot 10^{15}\,\boldsymbol{m}^2 & \left(2.767\cdot 10^{7}\right)\,\boldsymbol{m} & -2.942\cdot 10^{8}\,\boldsymbol{m} & \left(5.533\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(2.491\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -1.001\cdot 10^{16}\,\boldsymbol{m}^2 & \left(3.171\cdot 10^{7}\right)\,\boldsymbol{m} & -3.156\cdot 10^{8}\,\boldsymbol{m} & \left(6.343\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(2.835\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -1.203\cdot 10^{16}\,\boldsymbol{m}^2 & \left(3.572\cdot 10^{7}\right)\,\boldsymbol{m} & -3.367\cdot 10^{8}\,\boldsymbol{m} & \left(7.144\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(3.195\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -1.419\cdot 10^{16}\,\boldsymbol{m}^2 & \left(3.969\cdot 10^{7}\right)\,\boldsymbol{m} & -3.575\cdot 10^{8}\,\boldsymbol{m} & \left(7.938\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(3.57\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -1.649\cdot 10^{16}\,\boldsymbol{m}^2 & \left(4.363\cdot 10^{7}\right)\,\boldsymbol{m} & -3.779\cdot 10^{8}\,\boldsymbol{m} & \left(8.726\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(3.962\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -1.892\cdot 10^{16}\,\boldsymbol{m}^2 & \left(4.753\cdot 10^{7}\right)\,\boldsymbol{m} & -3.981\cdot 10^{8}\,\boldsymbol{m} & \left(9.507\cdot 10^{7}\right)\,\boldsymbol{m}\\ \left(4.368\cdot 10^{16}\right)\,\boldsymbol{m}^2 & -2.149\cdot 10^{16}\,\boldsymbol{m}^2 & \left(5.141\cdot 10^{7}\right)\,\boldsymbol{m} & -4.18\cdot 10^{8}\,\boldsymbol{m} & \left(1.028\cdot 10^{8}\right)\,\boldsymbol{m}\end{bmatrix}$$

$$\operatorname{rank}(M)=?\qquad\qquad \operatorname{rank}\left(\overrightarrow{\frac{M}{\operatorname{SIUnitsOf}(M)}}\right)=4$$

Значение должно быть матрицей с действительными числами.

Fig. 27. Calculation of the rank of the dimensional matrix

The problem was solved after the matrix, or rather, its elements (see the arrow to the left - the vectorization operator) was deprived of dimension by dividing by a function called SIUnitsOf (SI units). Examples of this function are shown in Fig. 28: four hundred pounds is about 181 and a half kilograms, and 5 feet and 5 inches is a meter and 65 centimeters (again, approximately). The kilogram and meter are the basic units of the SI. The SIUnitsOf function, as it were, takes us back - to the days of working with dimensionless computational tools: spreadsheet processors, programming languages, etc..

$$m:=400\ \boldsymbol{lb}\qquad\qquad \frac{m}{\operatorname{SIUnitsOf}(m)}=181.437$$

$$l:=5\ \boldsymbol{ft}+5\ \boldsymbol{in}\qquad\qquad \frac{l}{\operatorname{SIUnitsOf}(l)}=1.651$$

Fig. 28. Removal of physical quantities of dimension

When solving problems, even in the environments of advanced physical and mathematical packages, it is often, alas, necessary to remove variables of dimensions at some stages of the calculation or in the entire calculation.
Here and in other cases, AI will be very useful. Including when working with empirical and pseudo-empirical formulas [7, 11], when plotting graphs, creating animations, etc.
Last example.
The first author, as an energy chemist by education, also remembers Mendeleev's aphorism that burning oil is the same as heating the stove with banknotes, and the fact that Dmitry Ivanovich created formulas for calculating the heat of combustion of fuel, including oil. These formulas are a bunch of empiricism incomprehensible to many and complex variable names with superscripts and subscripts. One example can be seen here [12]. These formulas are waiting to be implemented with units. We leave it to the readers.

General conclusion. Mankind, in its entire long history - the history of technical culture, somehow learned how to work correctly with units of measurement. The time has come to teach this to a computer using the methods and means of artificial intelligence. These methods can simultaneously perform educational functions: through drop-down prompts (see Fig. 1, 2, 5, 11, 12, 15 and 27) and other tools built into physical and mathematical packages for teaching users how to work correctly with physical, chemical, economic, informational and other quantities.

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