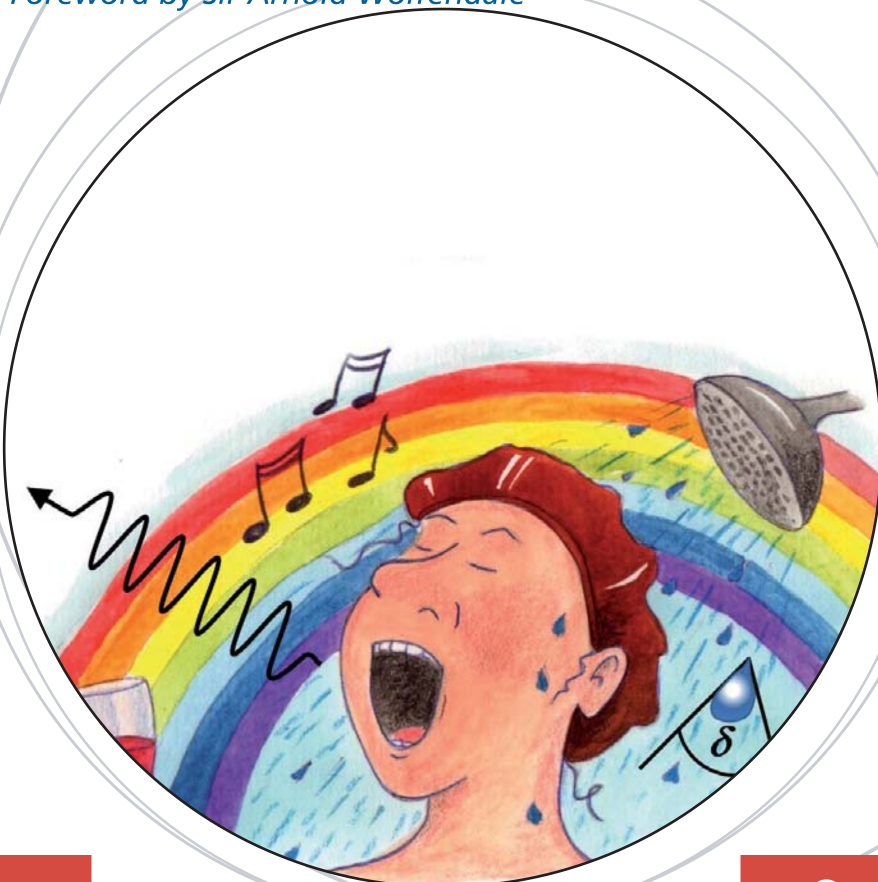
JO HERMANS
With illustrations by Wiebke Drenckhan

Physics in Daily Life

Foreword by Sir Arnold Wolfendale



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Physics in Daily Life

ABOUT THE AUTHORS

Prof. L.J.F. Hermans is Emeritus Professor of Physics at Leiden University, The Netherlands. In addition to his academic teaching and research career he was quite active in promoting and explaining science for the general public. In this context he published, among others, a book about Every-day science (in Dutch) and two books about Energy (in Dutch and English). He is presently Science Editor of Europhysics News. He was appointed Knight in the Order of Oranje Nassau by Queen Beatrix in 2010.

Wiebke Drenckhan is CNRS researcher at the *Laboratoire de Physique des Solides* at the outskirts of Paris, where she tries to unravel the physical properties of soft materials, such as foams or emulsions. In her spare time she finds great pleasure in letting scientific issues come to life with pen and paper in the form of illustrations or cartoons.

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This is a collection of ‘Physics in Daily Life’ columns which appeared in Europhysics News, volumes 34 - 42 (2003 – 2011)

Mise en pages : Patrick Leleux PAO

Imprimé en France
ISBN : 978-2-7598-0705-5

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FOREWORD

The history of Physics in Europe is one of brilliance and the sun is still shining, indeed it is getting ever brighter, despite the economic problems. The European Physical Society is a composite of all the national physical societies and it occupies an important role in providing advice to its members and a forum for discussion.

Its house journal, *Europhysics News*, is an exciting small publication, packed with interesting articles about conferences, national societies, highlights from European journals and 'features'. In addition there has been, for the past decade, a page entitled 'Physics in Daily Life'. The present volume is a collection of these pages and is a feast of erudition and humour, by way of the excellent accompanying cartoons as well as the subject matter.

It is easy for those of us steeped in our disciplines, of astrophysics, condensed matter, nuclear physics, or whatever, to think that 'everyday physics' is child's play compared with the deep subtleties of our chosen subjects. Surely, if we can understand the mysteries of parallel universes, the behaviour of superconductors or exotic atomic nuclei, the V-shaped pattern of a duck's wake in the lake at the local Wildfowl Park will be a 'piece of cake'. However, it would be wise, before telling ones child/grandchild/lady or gentleman friend or… to read the contribution 'Brave Ducks' herein. Quite fascinating…

In a similar vein, the Astrophysicist who knows all about the recently found bubbles in the interstellar medium just outside the heliopause, and the Local Bubble in which the solar system is immersed, had better read the 'Bubbles and Balloons' piece before setting himself or herself up as an authority on such matters at the next Christmas Children's Party.

Michael Faraday, that physicist of genius, whose discoveries led to the electrical power industry amongst many other things, lectured for one hour on the physics and chemistry of the candle flame. He probably knew the points made in 'Amazing Candle Flames' (contribution number 39) but I didn't. Henceforth, my over-dinner description of the candle flames at the table will be the envy of my guests – even the physicists and chemists amongst them (unless they happen to belong to the EPS).

Turning to our activities on the high seas, where many of us use our SKI funds ('Spending the kids' inheritance') to take exotic cruises, we have the oft-sought 'green flash' from the sun as it sinks below the horizon. Wearing our tuxedos and leaning over the rail with our new-found friends, we have languidly explained what we should have seen as the sun gently disappeared (only occasionally does it make an appearance). Beware, however, your explanation may not be quite right – 'Fun with the setting sun' (contribution number 17) will put you right. Even one's description of why the sea sometimes looks blue may turn out to have been wrong! Better to take with you an absorption curve for water, from 400-700 nm, to nonchalantly fish out of your pocket at the appropriate moment.

Now to taxi-drivers, most are sources of information, freely imparted, and their views are strongly held. In order to keep one step ahead it would be wise to dip into our compendium and produce such gems as 'Hearing the Curtain' (contribution number 16) which relates to the reason why we all like to sing in the bath. The driver will be enthralled when you explain that the sound absorption properties of the curtains are the same whether they are drawn shut or quite open. Indeed it may lead to some interesting descriptions of sights that the taxi driver himself has witnessed during his late night excursions.

So, what about this collection? For me, at least, it scores 10/10 and I recommend it to all who have an interest in the physical world and explanations of what seem to be – but are often not – simple phenomena. Not only that, but buy it for your friends and relatives.

Arnold Wolfendale

(*Sir Arnold Wolfendale FRS is a Past-President of the EPS. He is emeritus Professor of Physics in Durham University, UK*)

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1

The human engine (and how to keep it cool)

We don't usually think of ourselves in that way, but each of us is an engine, running on sustainable energy. It differs from ordinary engines in more than just the fuel. The human engine cannot be shut off; for instance, it keeps idling even if no work is required. This is needed to keep the system going, to keep our heart pumping, for example, and to keep the temperature around 37 °C. Because – and here is another difference – our human engine works in a very small temperature range.

It's interesting to look at this a bit more quantitatively. Our daily food has an energy content of 8 to 10 MJ. That, incidentally, is equivalent to a quarter of a litre of gasoline, barely enough to keep our car going on the highway for about 2 minutes. Those 8 to 10 MJ per day represent just about 100 W on a continuous basis. Only a small fraction is needed to keep our heart pumping, as we can easily estimate from a $p\Delta V$ consideration (p being on the order of 10 kPa and ΔV on the order of 0.1 litre, with a heart beat frequency of around 1 Hz).

In the end, those 100 W are released as heat: by radiation, conduction and evaporation. Under normal conditions, sitting behind our desk in our usual clothing in an office at 20 °C, radiation and conduction are the leading terms, while evaporation gives only a small contribution. But when we start doing external work, on a home trainer, for example, the energy consumption goes up, and so does the heat production. Schematically, the total energy consumption P_{tot} *vs.* external work P_{work} is shown in the figure, where an efficiency of 25% has been assumed. Thus, if we work with a power of 100 W, we increase the total power by 400 W, and the heat part P_{heat} by 300 W.

Now our body must try to keep its temperature constant. That's not trivial: if we don't change clothing, or switch on a fan to make the temperature gradients near our skin somewhat larger, the radiation and conduction terms cannot change much. They are determined by the difference between the temperature of our skin and clothing on the one hand, and the ambient temperature on the other. When working hard, we increase that difference only slightly. Granted, due to the enhanced blood circulation, our skin temperature will get closer to that of our inner body, but the limit is reached at 37 °C.

Fortunately, there is also the evaporation term. Sweating comes to our rescue, as also, of course, does drinking! Each additional 100 W of released heat that has to be compensated by evaporation requires a glass of water per hour (0.15 litre, to be more precise). The various terms are schematically shown in the figure.

One conclusion: heavy exercise requires evaporation. Don't try to swim a 1000 m world record if your pool is heated to 37 °C. You might not live to collect your prize, because where would the heat go?

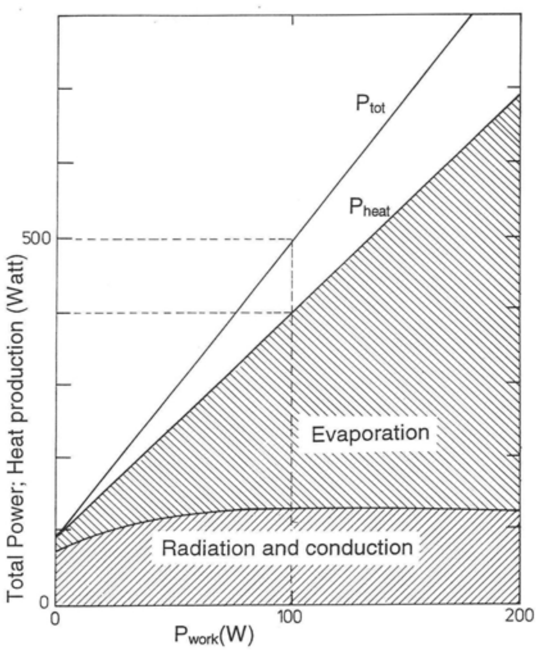

Image 1.1 | Total energy production, heat production and heat release *vs*. external mechanical power, schematically.

2

Moving around efficiently

Ever considered the efficiency of a human being moving from A to B? Not by using a car or a plane, but just our muscles. Not burning oil, but food.

Many physicists will immediately shout: A bike! Use a bicycle! It is because we all know from experience that using wheels gets us around about five times as fast as going by foot with the same effort.

But just how efficient is a bike ride? First, we have to examine the human engine. The power we produce is easily estimated by climbing stairs. If we want to do that on a more or less continuous basis, one step per second is a reasonable guess. Assuming a step height of 15 cm and a mass of 70 kg, this yields a power of roughly 100 W. Mountain climbers will find the assumed vertical speed quite realistic, since it takes us about 500 m high in an hour, and that is pretty tough exercise.

Riding our bike is pretty much like climbing the stairs: same muscles, same pace. In other words, we propel our bike with about 100 W of power. But that is not the whole story. The efficiency of our muscles comes into play. For this type of activity, the efficiency is not so bad (a lot better than *e.g.* weight lifting). We may reach 25%. The total energy consumption needed for riding is therefore around 400 W.

What does this tell us about the overall transport efficiency? How does this compare with other vehicles? Now it's time to do a back-of-the-envelope calculation. If we express 400 W of continuous energy use in terms of oil consumption per day, we find pretty much exactly one litre per day, given that the heat of combustion for most types of oil and gasoline is about 35 MJ per litre. In other words: if, for the sake of the argument, we ride for 24 hours continuously without getting off our bike, we have used the equivalent of 1 litre of gasoline for keeping moving. How far will that get us? That, of course, depends on the type of bike, the shape of the rider, and other parameters. If we take a speed of 20 km/h as a fair estimate, the 24 hours of pedaling will get us as far as 480 km. In other words: a cyclist averages about 500 km per litre.

That's not bad, compared to a car, or even a motorbike. So, we should all ride our bike if we want to conserve energy? Careful, there is a catch. We have been moving on food, not gasoline or oil. And it takes a lot more energy to get our food on the table than its energy content may suggest. A glass of milk, for example, takes roughly 0.1 litre of oil, and a kg of cheese even about 1 litre. It's because the cow has to be milked, the milk has to be cooled, transported, heated, bottled, cooled again, transported again, etc. It's the same (or worse) for cheese, meat, etc.

Conclusion: Riding our bike is fun. It's healthy. It keeps us in good shape. And, if we have to slim down anyway, it conserves energy. Otherwise – I hate to admit it – a light motorbike, if not ridden too fast, might beat them all.

3

Hear, hear

Even a tiny cricket can make a lot of noise, without having to 'refuel' every other minute. It illustrates what we physicists have known all along: audible sound waves carry very little energy. Or, if you wish, the human ear is pretty sensitive – if the sound waves are in the right frequency range, of course.

Exactly how our ears respond to sound waves has been sorted out by our biophysical and medical colleagues, and is illustrated by the familiar isophone plots that many of us remember from the textbooks. They are reproduced here for convenience.

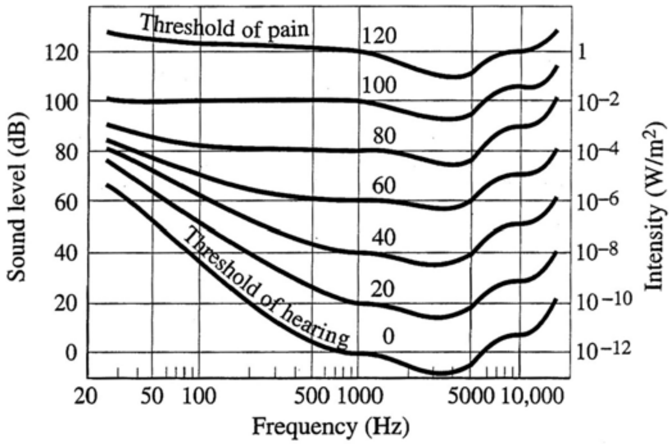

Image 3.1 | Isophone curves, with vertical scales in dB (left) and W/m^2 (right).

Each isophone curve represents sound that seems to be equally loud for the average person.

The figure reminds us that the human ear is not only rather sensitive, but that it also has an astonishingly large range: 12 orders of magnitude around 1 kHz. This is, in a way, a crazy result, if we think of noise pollution. It means that, if we experience noise loud enough to reach the threshold of pain, and we assume that the sound intensity decays with distance as $1/r^2$, we would have to increase the distance from the source r by a factor of 10^6 to get rid of the noise. Or, if we stand at 10 m from the source, we would have to walk away some 10 000 km.

Here we have assumed that the attenuation can be neglected, since we have been taught that sound wave propagation is an adiabatic process. Obviously, real life isn't that simple. There are several dissipative terms. For example, think of the irreversible heat leaks between the compressed and the expanded air. An interesting feature here is that the classical absorption coefficient is proportional to the frequency squared, which makes distant thunder rumble. Then there is attenuation by obstacles. In addition, there is the curvature of the earth, and the curvature of the sound waves themselves, usually away from the earth due to the vertical temperature gradient. Without loss terms like these, forget a solid sleep.

A second feature worth noticing is the *shape* of the curves. Whereas the pain threshold curve is relatively flat, the threshold of hearing increases steeply with decreasing frequency below 1 kHz. If we turn our audio amplifier from a high to a low volume, we tend to loose the lowest frequencies. The 'loudness control' is intended to compensate for this.

Finally, it is interesting to notice the *magnitude* of the sound intensity. How much sound energy do we produce when we speak? Let us assume that the listener hears us speak at an average sound level of 60 dB, which corresponds to 10^{-6} W/m^2 as seen from the right-hand vertical scale. Assuming that the listener is at 2 m, the energy is 'smeared out' over some 10 m^2. This means that we produce, typically, 10^{-5} W of sound energy when we talk. That is very little indeed. During our whole life, even if we talk day and night and we get to live 100 years, we will not talk for more than 10^6 hours. With the above 10^{-5} W, this means a total energy of 10 Wh. Even at a relatively high price of € 0.50/kWh, this boils down to less than one cent for life-long speaking. Cheap talk, so to speak.

4

Drag'n roll

Whether we ride our bike or drive our car, there is resistance to be overcome, even on a flat road; that much we know. But when it comes to the details, it's not that trivial. Both components of the resistance – rolling resistance and drag – deserve a closer look. Let's first remember the main cause of the rolling resistance. It's not friction in the ball bearings, provided they are well greased and in good shape. It's the tires, getting deformed by the road. In a way, that may be surprising: the deformation seems elastic, it's not permanent. But there is a catch here: the forces for compression are not compensated for by those for expansion of the rubber capricious deviations through the seasons: the solar time on the sundial will almost always run slow or fast with respect to the 'mean solar time' on our watch. It's all determined by the rotation of the earth around its axis, combined with its orbit around the sun.

The first thing we realise is that, from one day to the next, the earth needs to rotate a bit more than 360 degrees for us to see the sun in the South again. The reason is obvious. During a day, the earth moves a bit further in its orbit around the sun and thus needs to turn a little extra to bring the sun back to the same place (remember that the rotational direction of the earth around its axis *and* of its orbit around the sun are both counterclockwise). Now, if the earth were well-behaved, and would move in a circular orbit around the sun, with its rotational axis perpendicular to its orbital plane, this would be the end of the story.

But there are two complications, both of which cause deviations. The first one is the *elliptical* orbit of the earth. In fact, the earth is 3% closer to the sun at the beginning of January than at the beginning of July. So, the globe must rotate just a bit longer in January to have the sun back in the South than in July; just think of Kepler's law. The result is that the solar time will gradually deviate from the time on our watch. We expect this 'eccentricity effect' to show a sine-like behaviour with a period of a year.

There is a second, even more important complication. It is due to the fact that the rotational axis of the earth is not perpendicular to the ecliptic, but is tilted by about 23.5 degrees. This is, after all, the cause of our seasons. To understand this 'tilt effect' we must realise that what matters for the deviation in time is the variation of the sun's *horizontal* motion against the stellar background during the year. In mid-summer and mid-winter, when the sun reaches its highest and lowest point of the year, respectively, the solar motion is fully horizontal, so its effect on time is large. By contrast, in spring and autumn, the sun's path also has a vertical component, which is irrelevant here. But it makes the horizontal component smaller in these parts of the year, and so also its effect on time. This gives rise to a sine-like deviation having a period of *half* a year.

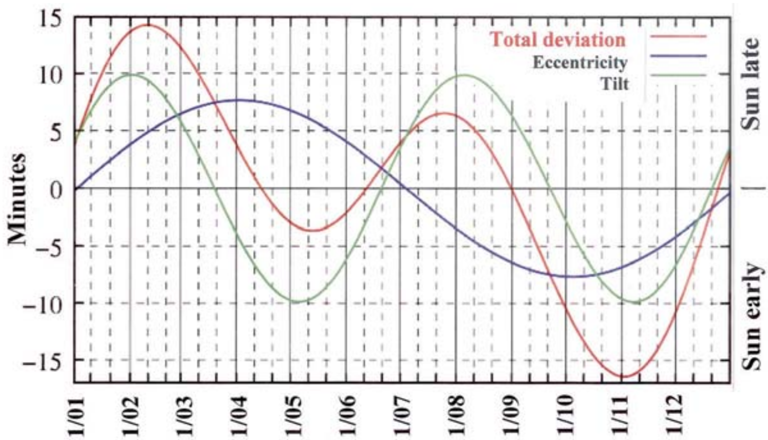

Figure 40.1 | Difference between solar time and 'mean solar time', and the separate contributions of the two underlying effects.

The two contributions are shown in the graph. Superposition of these 'single and double frequency' curves yields the total deviation of the 'solar noon' from the 'mean solar noon' on our watch. We see that around February 11 the sun is about 15 minutes later than average, and around November 3 about 15 minutes earlier.

So, a sundial in our front yard may be quite charming, but understanding its readings requires a scientist.