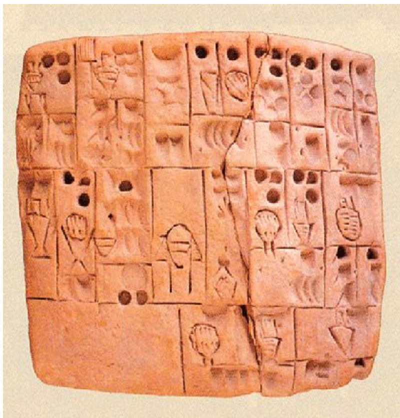
Swords and Beer

Importance of Beer for Civilization and thus Swords

Advanced

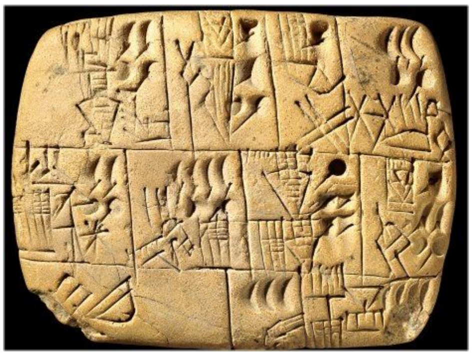
- Of course you (being probably male) feel strongly that swords and beer are somehow connected, you're just not quite sure about how these two essential items connect *scientifically*. There is no doubt, however, that after prolonged sword fight exercises the guys needed something to drink in bulk, and that couldn't possibly be water.
  - Well, there is more to swords and beer than meets the ~~eye~~ thirsty throat. Scientifically, the chain of reasoning is: No beer → no settlements → no metallurgy → no swords.
  - Easy. Let's see if that could be true in the first part of this module. Then let's see how doing some scientific work with beer helps to understand key issues in steel engineering.
- Can there be a halfway advanced civilization, able to smelt metals, without beer? As far as I know, if there were some, we still need to find them. But it's probably not worth the effort. The ones we found had beer or something coming close.
  - The pictures below prove that. The first one shows a proto cuneiform clay tablet from Mesopotamia / Uruk. It is about 5.000 years old and thus one of the oldest artifacts with some kind of writing on it. It predates **cuneiform** (that's why it's "proto"). One would tend to assume that only supremely important stuff was recorded that way. The tablet records the ingredients needed for making beer. If that's not important, what is?



Beer recipe from Uruk, about 5000 years old.
See also Peter Damerow's article

Source: Elke Maier/ Peter Damerow, "Die Bierbrauer von Baylon", in: Max Planck Forschung, 4, 2011, p. 94

  - Some scientists today actually do believe that hunters and gatherers only became farmers and sessile because they needed to grow cereals for making beer. I couldn't agree more. Who needs bread as long as you have beer and some mammoth steak for a good and prolonged barbecue party? Here is a quote:
    "It has been argued, that it was the discovery of the intoxicating effect of the alcohol contained in beer rather than the use of grain for other foodstuffs that caused the transition from hunting and gathering to living in stable settlements, domesticating animals, and cultivating the soil. This transition emerged around 7000 BC. in the border territory of the alluvial plane of Mesopotamia". It comes from the learned article of **Peter Damerow**, the top expert on this topic. You may want to look at his article because quoting from it gives you that intellectual air that might help to score with women (a part of humanity more given to talking than to the bulk intake of beer). Well, here is more material for whatever it is good for:



Record of the daily beer rations for workers

You clearly see the symbols for beer (triangular clay vessel; look at the picture below).
Probably from southern Iraq, Late Prehistoric period, 3100-3000 BC

Source: British museum Internet pages

- If you know the least little bit about cuneiform writing, you know that the tablet above must be at least from 3.200 BC because of the way "beer" is spelled out. If you don't know all that much about cuneiform or writing, here is the time line:

The evolution of the symbol for beer in cuneifom

Source: The blog of Leopoldo Costa; see below

- "The earliest written documents are Sumerian wage lists and tax receipts, in which the symbol for beer, a clay vessel with diagonal linear markings drawn inside it, is one of the most common words, along with the symbols for grain, textiles, and livestock. That is because writing was originally invented to record the collection and distribution of grain, beer, bread, and other goods."
says TOM STANDAGE in the book 'A HISTORY OF THE WORLD IN 6 GLASSES'. Walker & Company, New York, 2006, p. 14-36, in the adapted, illustrated and posted blog of Leopoldo Costa. You may want to read that article. Here is the link.

The old Sumerians must also have had a lot of lawyers that worked hard to make simple things complicated. There is no other way to explain how an easy-to-learn script evolved into a difficult and abstract entity that only made sense to overpaid experts. Just look at the development of the symbol for a female:

The evolution of the symbol for females in cuneifom
Timeline as above

Source: Common knowledge among the literati.

- Many tablets have been found that deal with making and distributing beer in the mesopotamian ancient world. Similar recordings exist from other old cultures, e.g. Egypt.
What they tell us, for example, is that some 4000 years ago in old Sumer a typical meal consisted of soup or porridge, bread, and beer. And these guys already had 9 different kinds of beer, counted it among the most basic food stables, composed hymns to the goddess **Ninkasi**, thanking her for teaching humans how to make it, and let the kids drink the stuff. It must have been a lot like present-day Bavaria.
Here is a picture demonstrating that:

Warpalas, King of Tyanan, prays in front of plant and storm God Tarhunza
Late Hittite, 8th century BC.

Source: Photographed in the Archaeology Museum Istanbul

- Those old Turks had their priorities right. You pray to your God in the correct way, and he gives you grapes for making wine and barley (in his left hand) for making beer. He doesn't have to give you women because those you get yourself; they are far easier to come by than wine and beer

Right now a bunch of German scientists, including archeologists, cuneiform and brewery experts, try to make beer as taught by these more than 4000 years old recipes.

- They use the Weihenstephan research facilities (of course in Bavaria) and already produced some beer that, according to the description, seems to taste like American beer: thin and slightly sour, with little alcohol and few gas (CO_2, making the bubbles).
  This is not acceptable in Bavaria. Some experts, however, maintain that the old ones could do better and that just more research and experiments are needed to produce decent Sumerian / Babylonian / Urukian beer.
  I could not agree more. There can never be too many experiments concerning beer.

Anyway, I now claim my first point to be proved. Beer is essential for throwing early civilizations together, and there certainly would be no metals and thus swords without that. Not to mention that forging swords is hard *and* hot work, pretty much impossible without beer.

- Now let's go on to do our own experiments with beer

Important Experiments with Beer

Here is an extremely illuminating experiment that you can do yourself with a decent kind of beer. It concerns a very general and important concept of Materials Science that carries right over to steel and sword-making.
The topic is the **decay of excited states**. There are lots of excited states out there in serious science, not to mention at parties, sports events, rock concerts, wedding nights and proto-wedding nights, and so on. However, I will only deal with the more boring excited states here.

- An excited state of some matter is a state where the energy of the piece of matter in question is larger than it ought to be. The excited matter will *relax* somehow and eventually come back to the unexcited *ground state* where it has just the right amount of energy. We scientists do call that "relaxation", by the way, and "relaxation times" or "relaxation approaches" are big words in serious physics.
  Let's look at a few examples of boring but excited matter:

  - **Radioactivity**. Radioactive atoms have an "excited" nucleus that eventually emits some particle to get rid of its surplus energy. We call that "radioactive decay" and the ground state is reached when all excited atoms have decayed into some other atom.
  - **Light emission**. Light sources contain excited particles ("hot" atoms, if it is just a hot wire in a light bulb, electrons and holes in an LED, ...) that eventually get rid of their surplus energy by emitting particles called "photons" or light. In semiconductors the relaxation process getting the material down to the ground state (after you switch off the energy source) is called "recombination"; in a light bulb we call it "cooling down".
  - **Cooling**. If your material is much hotter than the environment, it has more energy than necessary. It relaxes by sending off *phonons*, as we call the quantum mechanical "heat particles" in a crystal, to the cooler parts - for example the crucible its in. The **cooling down** curve follows exactly the same laws of decay as everything else here.

- **Foam decay**. Foam is an excited state of the corresponding liquid. Foam or froth has far more surface and thus *surface energy* than a "solid" piece of the liquid. Foam will thus eventually turn into a liquid because the foam particles, called bubbles, burst and condense. You should be able to see that right now by looking closely at your beer.
- There is far, far more. It is time to get ready for the experiments now.

	**Getting Beer Break**	

All the examples above have two things in common:

- The *first* common denominator is that you have some objects (that I will continue to call "particles") that decay into something else. A radioactive atom decays into some high-energy particle and some other atom, a "hot" atom, heavily vibrating and with some of its electrons on outer "shells", decays into a cold atom, vibrating only slightly and with all its electrons as close as possible, and a foam bubble decays into a droplet.
- The *second* common denominator is that the decay is "statistical". There is no way of telling exactly when a given particle will decay, we only can state something about the *probability* for a decay event.

Knowing this, we can now easily derive the universal law for the decay of excited states. All we need to assume is that the (differentially) small number ΔN of the particles that decay in the (differentially) small time Δt is proportional to the number N of undecayed particles that are still around.
In other words:

$$\text{Number of decays per time unit} = \frac{\Delta N(t)}{\Delta t} = \frac{d\,N(t)}{d\,t} \propto N = -\lambda \cdot N(t)$$

- This is a very simple little differential equation relating the first derivative **d*N*(*t*)/d*t*** of some unknown function ***N*(*t*)** to the function itself.
For the boundary condition $N(t = 0) = N_0$ it has the obvious solution

$$N(t) = N_0 \cdot e^{-\lambda t} = \text{exponential decay law}$$

- The proportionality constant λ has the dimension $[\lambda] = 1/s$. That means, of course, that $1/\lambda$ is (a bit imprecisely) the half-time constant of whatever decays. The precise half-time, where exactly half of some stuff has decayed, would of course be: $T_{half} = (1/\lambda) \cdot \ln(0{,}5) \approx 0{,}69/\lambda$
(This is an advanced module after all).

We derived a rather general relation, the exponential decay law, for how things develop if matter is excited. It's called the "relaxation approach" and permeates a lot of Materials Science.

- As far as sword making is concerned, the equation right above essentially covers the cooling down of hot steel if it is no longer heated but put into a cooler environment. Cooling steel (or anything else) in air for example, or in cold water when you "quench" it, follows that equation. Just substitute the temperature T for the particle number N. You can do that since the temperature is just a measure for the number of "hot" particles in there. The half-time constant λ might get a different name, too, in this case. The math, however, is exactly the same.
Time for another beer break (get some more, you'll need it).

Major exhibits (actually the only kind they have) in the beer collection of the Carlsberg brewery.

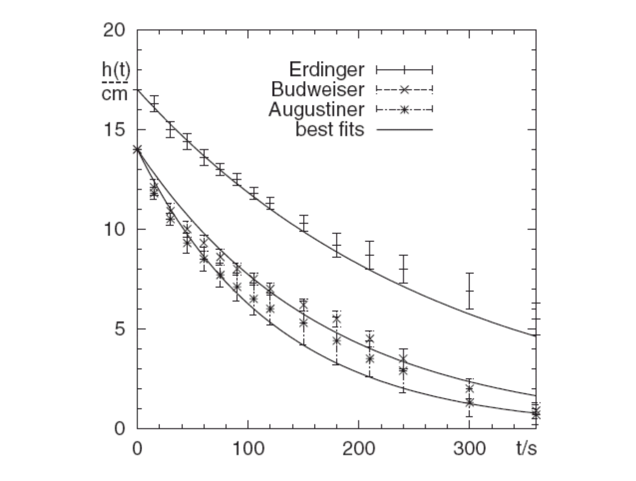
Source: Photographed right there

- This is the largest collection of (full) beer bottles in the world: 21.930 specimen! You find it in the Carlsberg brewery (museum) in Copenhagen, Denmark.

Having you back, I will now give you the good news: You, personally, can investigate all of the exciting stuff about the decay of excited states from above with a few bottles of beer. Is this great, or what? What you do is:

1. Get some beer and a clean glass. The glass should be cylindrical with a constant diameter.
   Also get a ruler, a pencil, and something to write on, so you can record the measurements. A secretary or somebody else, preferably of the other sex (I need to keep this gender mainstreamed), who is up to this and possible follow-up tasks, would also be OK.
2. Pour some beer into the glass, producing a nice head of froth.
3. Measure the height of the froth in as small time intervals as you can manage, for as long as it takes the froth to more or less disappear.
4. Plot the data on a graph showing the height of the froth versus time.
5. Drink the beer. Discarding it would be wasteful and obnoxious to all those poor scientists in less fortunate countries who can't afford this kind of sophisticated studies.

- The height of your head of foam is just a measure of the number of bubbles in there. What you should get if the theory is correct *and* your experimental skills were up to the task, is a curve like one of these:



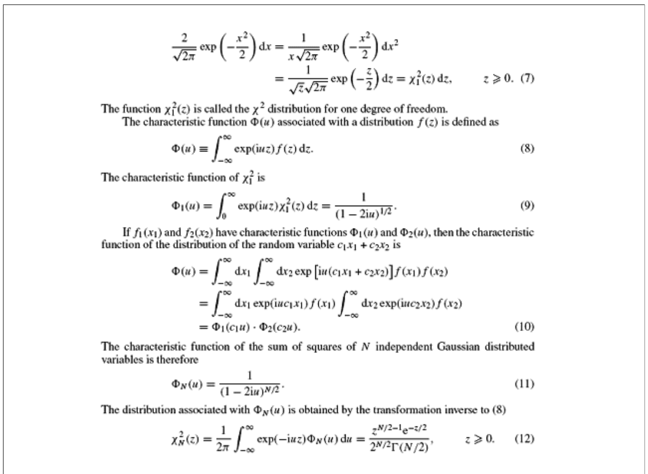
The height of the froth for different kinds of beer as function of time.
Shown are the data and the best fits.

Source: The Noble prize winning article. "Demonstration of the exponential decay law using beer" from A Leike, in: Eur. J. Phys. 23 (2002) 21–26

- The solid lines are curves based on the equation from above. They have been calculated from the measured data in a process called "fitting".

There is a lot we can learn from this.

- *First*, it was **Arnd Leike** from the physics department of of the University of Munich in Bavaria (**!**) who won the **2002** physics *Ig* Nobel prize for demonstrating that beer froth obeys the mathematical law of exponential decay and not me - even so I did this kind of experiment with my students far earlier, around 1970.
  However, I did not write a paper about it. But who wants to win the Ig Nobel prize anyway? "*The Ig Nobel Prize winner has done something that first makes people LAUGH, then makes them THINK. Technically speaking, the Igs honor people whose achievements "cannot or should not be reproduced.*" says the Web site.
  I think the Ig Nobel prize guys are crazy. You cannot reproduce an experiment like this often enough.
- *Second*, it is obvious that the exponential decay law covers beer rather well - but not perfectly. The "Augustiner", for example, does less well than the others.
  We can only conclude, in open defiance of the Ig nobel prize guys, that far more work is necessary to really understand the nature of beer, the subtle differences between the various kinds, if the kind of beer mug you use is important, if the person of the other sex who records the data does influence the data, and so on and so forth.
  So get to it! If there was a good reason to drink beer, here it is.
- *Third*, the experiment can be used to teach the kids about the importance of math. Here is a small excerpt from Arnd Leike's prize-winning paper, showing what it takes to work with beer in style:



$$\frac{2}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right)\mathrm{d}x = \frac{1}{x\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right)\mathrm{d}x^2$$
$$= \frac{1}{\sqrt{z}\sqrt{2\pi}}\exp\left(-\frac{z}{2}\right)\mathrm{d}z = \chi_1^2(z)\,\mathrm{d}z, \qquad z \geqslant 0. \quad (7)$$

The function $\chi_1^2(z)$ is called the χ^2 distribution for one degree of freedom.

The characteristic function $\Phi(u)$ associated with a distribution $f(z)$ is defined as

$$\Phi(u) \equiv \int_{-\infty}^{\infty} \exp(\mathrm{i}uz) f(z)\,\mathrm{d}z. \quad (8)$$

The characteristic function of χ_1^2 is

$$\Phi_1(u) = \int_0^{\infty} \exp(\mathrm{i}uz)\chi_1^2(z)\,\mathrm{d}z = \frac{1}{(1-2\mathrm{i}u)^{1/2}}. \quad (9)$$

If $f_1(x_1)$ and $f_2(x_2)$ have characteristic functions $\Phi_1(u)$ and $\Phi_2(u)$, then the characteristic function of the distribution of the random variable $c_1x_1 + c_2x_2$ is

$$\Phi(u) = \int_{-\infty}^{\infty}\mathrm{d}x_1 \int_{-\infty}^{\infty}\mathrm{d}x_2 \exp\left[\mathrm{i}u(c_1x_1 + c_2x_2)\right] f(x_1) f(x_2)$$
$$= \int_{-\infty}^{\infty}\mathrm{d}x_1 \exp(\mathrm{i}uc_1x_1) f(x_1) \int_{-\infty}^{\infty}\mathrm{d}x_2 \exp(\mathrm{i}uc_2x_2) f(x_2)$$
$$= \Phi_1(c_1u)\cdot\Phi_2(c_2u). \quad (10)$$

The characteristic function of the sum of squares of N independent Gaussian distributed variables is therefore

$$\Phi_N(u) = \frac{1}{(1-2\mathrm{i}u)^{N/2}}. \quad (11)$$

The distribution associated with $\Phi_N(u)$ is obtained by the transformation inverse to (8)

$$\chi_N^2(z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\exp(-\mathrm{i}uz)\Phi_N(u)\,\mathrm{d}u = \frac{z^{N/2-1}\mathrm{e}^{-z/2}}{2^{N/2}\Gamma(N/2)}, \qquad z \geqslant 0. \quad (12)$$

Beer and some Math

Source: The Noble prize winning article. "Demonstration of the exponential decay law using beer" from A Leike, in: Eur. J. Phys. 23 (2002) 21–26

You keep up the good work - I must stop now. The wife, ably assisting so far, has grown into an excited state and needs some help with the relaxation.