12.2.4 Sharpness

Defining and Measuring Sharpness

Your sword or knife that's just lying there is either sharp or blunt. So sharpness is a *static* property. Well, yes, but there are properties closely related to sharpness that are more dynamic:

- Retaining (or loosing) sharpness while *using* the blade.
- Reconstituting sharpness after it was lost.

And now I have opened a rather large can of exceedingly squiggly worms! Let me make one thing very clear right away:

No, I don't have that easy fail-proof recipe for keeping your blades sharp

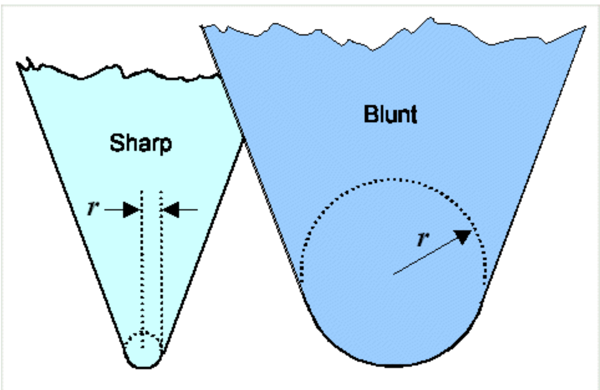
I have enough trouble to keep my own blades (medium) sharp

- All I can give you is a little "theory" of sharpness and retaining same. But that is not overly helpful for sharpening a blade. It is a bit like playing the piano (or any other musical instruments): Knowing all about the theory of musical notation and how that transfers into hitting the right key the right way at the right time, will not a piano player make. And the top players (who do certainly know the theory) don't know exactly why they are somewhat better at it then the second (still very good) tier of players.
  Some top experts can sharpen your sword better than "normal" experts but nobody knows what, exactly, they do differently. That's why sharpening a blade by hand is still an art. Sharpening blades by machines is different. The razor blades you buy are all extremely sharp (even so there are some differences between brands) and come straight from a machine.

For reasons not all that clear to me, the concept of sharpness did not receive much scientific attention until quite recently. References 1 and 2 (freely available in the Net) give examples of recent papers dedicated to the subject; their literature lists will lead you on if you like scientific fights and heavy math. What I learned from perusing some more publications is that there is no general agreement on how to define and measure sharpness. Greatly simplified, two basic ways of defining the sharpness of a given blade by a *number* are pursued:

1. Sharpness relates to the geometry of the blade, in the most simple case it relates to the inverse of the *radius of curvature* of the edge.
2. Sharpness relates to the *performance* of the blade, e.g. how deep it cuts into a standard substrate for a given force pushing it down.

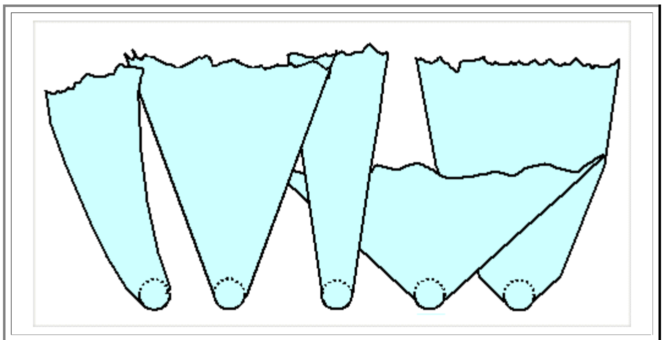
- The picture below gives an idea of how one could relate sharpness to the *radius of curvature* of a blade:



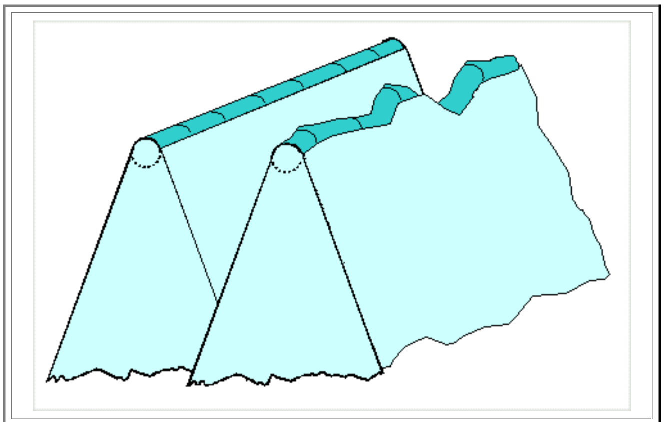
Sharpness demands a small radius of curvature at the blade edge

- Sharpness sort of begins at a radius of curvature of a few micrometers (µm). If you want "razor-sharp", you need to do better: A radius of 0.01 µm (=10 nm) is a good number then. The limit, of course, is the size of an atom (imagine the circle in the picture to be an atom), giving a radius of about 0.0001 µm or 0.1 nm. That would be a more than 10.000 fold improvement on sharpness relative to a 1 µm radius.
  I'm not sure if anybody has made a length of blade "atomically" sharp. But one-atom *tips* are common goods in "scanning tunneling microscopy" or STM.

But is it *only* the radius of curvature that determines sharpness? Of course not, consider the next two pictures:



Blades with identical radius of curvature but different shapes



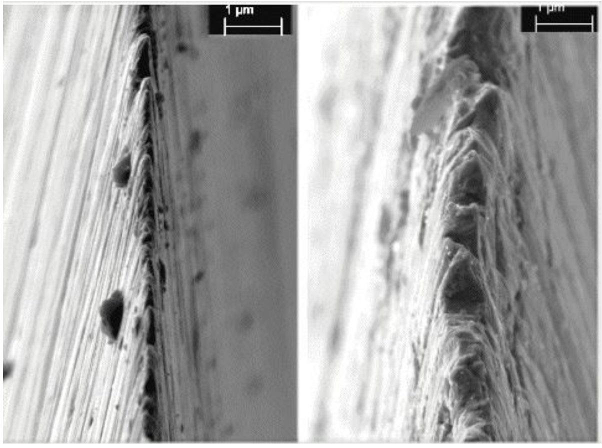
Ideal and real edge

- Not much needs to be said. The upper picture shows blades with the same radius of curvature but different blade geometries, Would they all be of identical *perceived* sharpness? Probably not - but it always depends of what you have in mind. Cutting hairs close to the skin without cutting the flesh certainly would profit from an optimized blade geometry like the one on the left. A meat cleaver wouldn't do so well with this shape, though.
  A more severe problem, however, results from the fact that most likely the geometry *changes* as you move along the blade. The radius of curvatures will not be the same at every point, the edge is not perfectly straight, and so on. My drawing skills cannot do justice to that but you get the idea. Irregularities along the blade are probably not so good for cutting straight into something by only pressing the blade down but might give better results compared to the "ideal" blade if you start "sawing". Saws do not have teeth just for looks, after all.

To conclude:

1. The (average) radius of curvature of your blade is not a *unique* and *precise* measure of the sharpness of your blade. But the trend is clear: A smaller radius of curvature will tend to increase the sharpness.
2. The (average) radius of curvature of your blade is not a *convenient* indication for the sharpness because it is difficult to measure. Cut your blade and look at the cross-section in a light microscope? Won't work, you need far higher resolution than what a light microscope has to offer. You need a (scanning) electron microscope! Sharpness is nanoscience!
3. Getting numbers for the radius of curvature thus is possible but not convenient.

- Indeed, if you look for high-magnification pictures of blade cross-sections in the Net, you won't find many, if any - as long as you do not hit on the pages of "scienceofsharp". This site features many excellent pictures that were taken in a "scanning electron microscope" (SEM); here are a few:



Rather good edge (left), and a somewhat crumbly one (right)

Source (for all SEM pictures here): from the sciencеofsharp web page
Whoever you are (the site doesn't reveal the maker), thanks a lot for sharing!

About as sharp as it can get

- It's not easy to obtain an edge like that! Don't ask me how to do it! Consult the page I mentioned.

But now let's look at the second way of defining sharpness. You measure how well a given blade cuts some test material. Easier said than done. What kind of material do you use? How is the cutting done? Just by (statically) pressing the blade on the target material, by (dynamically) hitting the target? With or without "drawing" the blade during the hit? Or would you do a repeated kind of sawing motion?
The Japanese already judged the sharpness of their blades by hitting a target and observing how deep the cut went. I have covered that already. Starting in the 16th century they formally judged the sharpness of their swords by having experts cut through piled-up bodies (hopefully already dead). The result was inscribed on the tang of the blade. Good blades in the hand of expert testers cut easily through two if not three bodies piled on top of each other. I have dealt with the shortcomings of this method already; use the link.
In the Western world no "standardized" testing like this was done but from old pictures you get the impression that there were some inofficial demonstrations of what an expert could do with a good, sharp blade.
Nowadays we need to be more objective and quantitative. So a machine does the test and takes numbers while it's doing so. We also use standardized, non-biological materials for the test. In essence, you do the reverse of a tensile test - a compressive test - pushing the blade to be tested down onto a target material. You may do that with constant

(slow) speed, monitoring the force needed to get to the depth as given by speed times time. Curves result that are not unlike the stress - strain curves treated in detail here, and from all of this you might derive a number for the sharpness of the blade tested. Reference 1 elaborates on this

- But this test only covers a kind of static cutting without moving the blade. That might cover the use of chisels but even then you tend to apply very large forces for very short times (you bang it with a hammer) and a static test might not cover that adequately. A blade that "won" the static test would be be inferior to a less sharp one if it blunts under the first stroke of the hammer, for example
  So let's not look at these tests anymore but turn to the pressing issue of *edge retaining*.

Retaining Sharpness

It's difficult to produce a sharp edge but it is impossible to retain a sharp edge if you use your blade frequently. What causes an edge to blunt, and how does that happen in detail? Rather tough questions, in particular the second one.
If you want answers to the detailed mechanisms of blunting, you need to look at the blunted blade with a high-powered electron microscope once more. That's not for everybody to do, and if you want pictures I must refer you to the the scienceofsharp site once more. Or even better, the article of our old acquaintance, **John D. Verhoeven** [3] who has written an extensive article with many (SEM) pictures about the subject.

The first question is easier to tackle - at least up to a point. All of us know one sure way of blunting a blade: Use it on something harder than the edge of the blade. Hit a decent stone with most blades and they are now definitely dull - if not fractured, dent and bend

- What happens is quite simple in principle. During impact (slow or fast) stress builds up on the blade edge and on the regions of the target that is hit by the edge. Hardness essentially measures the stress needed to induce plastic deformation (the yield stress) or, more loosely speaking, the onset of local cracking, and the softer material will "give" first, deforming in some way and thus blunting itself.
  Here are a few pictures showing what could happen:

Razor edge dulled by pulling it "sideways" over glass

- No surprise here. We just bend the edge by plastic deformation. This can be reversed to some extent by "stropping" because the sharp edge is still there. You "only" need to bend it back.

Edge dulled by drawing it across the lip of a glass beaker

- Here we have a bit of bending but mostly deformation by compression and "filing" or abrasion, resulting in a blunt edge. Glass is just quite a bit harder than most steels and thus acts as the file; the softer steel will be the filée

The hardness of a material is a reasonable well defined property, I have gone through that. Below are some old examples:

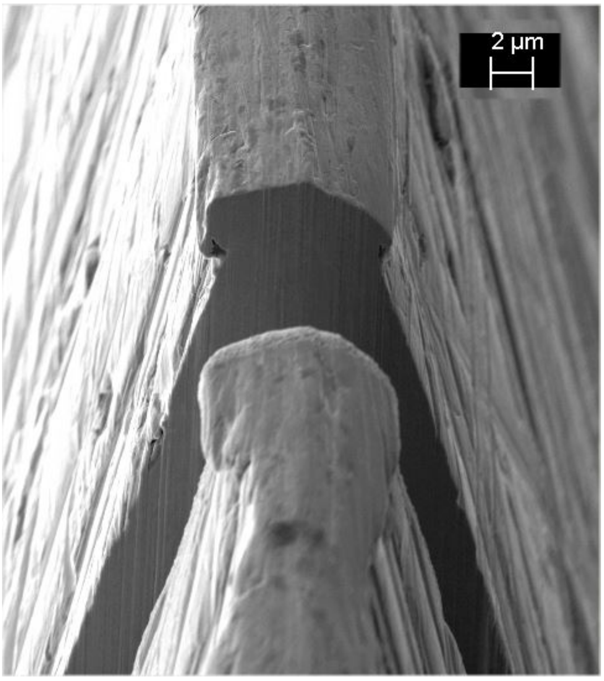
Metals	Vickers Hardness		Ceramics	Vickers Hardness
Tin (Sn)	5		Limestone	250
Aluminum (Al)	25		Magnesia (MgO)	500
Gold (Au)	35		Window glas	550
Copper (Cu)	40		Granite	850
Pure iron (Fe)	80		Quartz (SiO_2)	1200
Good tin bronze (Cu + 10% Sn)	220		"China" (Mostly Al_2O_3)	2500
Mild steel	140		Tungstencarbide (WC)	2500
Hardened steel (extreme)	900			
Polymers				
Polypropylene	7		Polyvinylchloride (PVC)	16
Polycarbonate	14		Epoxy	45

This table makes clear why our ancient forebears were reluctant to embrace early iron technology, considering that they had marvellous bronze blades that were generally superior to blades made from wrought iron or mild steel. It also makes clear why case-hardening the edge of a *steel* blade by quenching makes all the difference. You might end up with an edge that could, in principle, cut glass or granite! However, the first law of economics still applies! You pay dearly because there are plenty of problems, too:

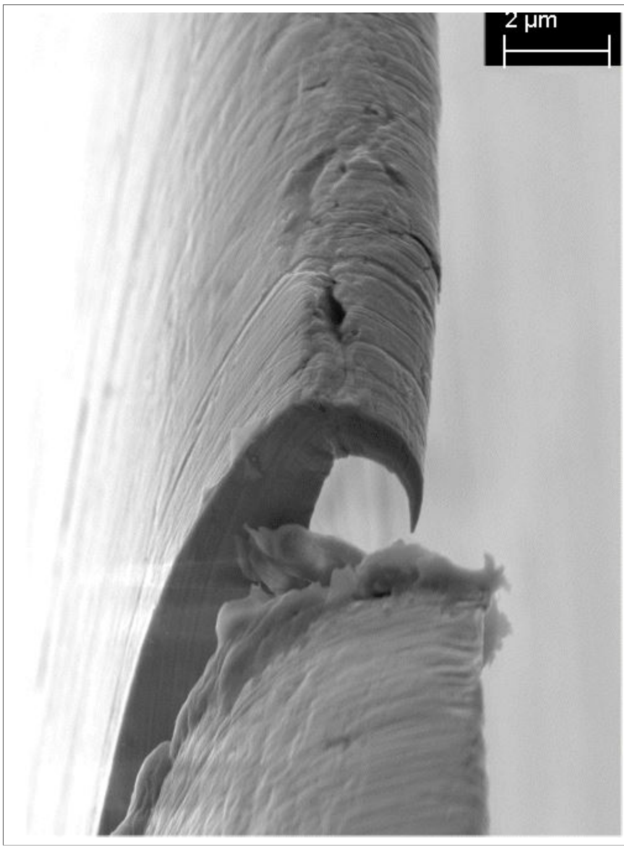
1. You need good and homogeneous carbon steel to start from.
2. You can re-sharpen your edge only a few times (if at all) because you quickly wear off the thin layer of hard martensite.
3. Your edge is rather brittle and chips easily.

The Japanese sword demonstrates what it takes to make the best out of extreme edge hardening while not yet in possession of superior modern steel that was liquid once and can be cast.

Now to the trickier points of blunting a blade. All of us know that our kitchen knifes will eventually become dull even if we never ever try to cut anything hard! One of the key words hear is "***wear***" and with that you open the door to hell. I'm not going through it. I'll just show two pictures demonstrating what can happen:



Formerly sharp (and hard) knife blade after cutting
about 7 m of heavy (but soft) cardboard



Razor edge after cutting a few cm of bond paper

- Paper is normally considered to be much softer than hard steel. But "steter Tropfen höhlt den Stein" (constant dripping wears the stone) as the Germans know, and the wear of the steel cylinders of rotary presses (used, e.g. for your newspaper) caused by their exposure to "soft" paper is a major issue in technology.

If you want to know more than that, you are best of by reading the article of Verhoeven and colleagues about wear of steel blades 4). Here is the abstract:
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> A study is presented on the relative wear rates of two carbon steels, a Damascus *(wootz)* steel and a stainless steel, using the Cutlery and Allied Trades Research Association (CATRA) of Sheffield England cutting test machine. The carbon steels and stainless steel were heat treated to produce a fine array of carbides in a martensite matrix. Tests were done at hardness values of HRC=41 and 61. At HRC=61 the stainless steel had slightly superior cutting performance over the carbon steels, while at HRC=41 the Damascus steel had slightly superior cutting performance.

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1) C: T. McCarhty, M.Hussey, and M. D.Gilchrist: "On the sharpness of straight edge blades in cutting soft solids: Part I - indentation experiments", Engineering Fracture Mechanics, Vol 74 (2007) p. 2205 -2224
Available in the Net

2) P. Stahle, A. Spagnoli, and M. Terzano: "On the fracture process of cutting", Procedia Structural Integrity, Vol. 3 (2017) P. 468 - 476

3) John D. Verhoeven: Experiments on Knife Sharpening
Directly published in the Net

4) John D. Verhoeven, Alfred H. Pendray, Howard F. Clark: "Wear tests of steel knife blades"Wear, 265 (2008) pp 1093 – 1099