Making Fluids into Solids with Magnets

Anyone can turn a liquid into a solid using an ice tray and a freezer. But can you solidify a fluid and then liquefy it within a few seconds? Actually, all you need is a strong magnetic field and a simple recipe for a magnetorheological fluid.

Such mixtures consist of particles suspended in a fluid. When the substance is exposed to a magnetic field, the particles align in such a way that the mixture becomes solid. When the field is removed, the particles return to their random state, and the substance liquefies. The degree of solidification depends on the inherent properties of the fluid and the strength of the applied magnetic field.

Magnetorheological fluids are not as common as a similar class of materials that solidify in the presence of electric fields. These electrorheological fluids have been incorporated in prototype brake systems, clutches, shock absorbers, engine mounts, actuators, control valves and even artificial joints [see "Electrorheological Fluids," by Thomas C. Halsey and James E. Martin, page 58].

Yet amateur scientists would be wise to experiment with magnetorheological fluids before they attempt anything with the electrical counterparts. Most electrorheological fluids require high voltages. For example, several thousand volts would be needed to solidify a mixture of corn oil and cornstarch. (The actual amount of electric current that would flow through the liquid would be quite low, however.)

Although present magnetorheological fluids are not as versatile as their electrical cousins, they do demonstrate the effect that so excites many researchers. The experiment described here can be performed on the kitchen table for less than $20.

A simple magnetorheological fluid is made of iron filings and corn oil. You can find iron filings at a toy store, at your workbench or at a machine shop. Specifically, you could empty the filings out of a toy magnetic sketch pad; you could scrape a piece of iron with a good metal file; or you could gather the iron filings produced by a metal lathe.

The size of the filings will determine the magnitude of the magnetorheological effect observed. The filings should be large enough to identify single particles with a magnifying glass but preferably less than half a millimeter long. Filings that are too large can easily be ground to a smaller size with a spoon and a hard surface. Be aware that iron will scratch the surface.

The type of oil needed to suspend the filings does not matter much. It just has to be more viscous than water, to slow down the rate at which the filings settle. I have used corn oil, linseed oil, silicone oil and motor oil. Corn oil is perhaps best: it is cheap and cleans up relatively easily with soap and water.

The filings and oil should be mixed in a small, clear container, such as a clean aspirin bottle, a plastic cup or, as I used, a 100-milliliter beaker. Just make sure that you can see down into the bottle. The fluid should consist of approximately 25 parts by weight oil to 100 parts by weight iron filings. The exact proportions of the constituents, however, are not critical to observing some kind of magnetorheological effect.

As for the magnetic field, almost any type of strong, permanent magnet will

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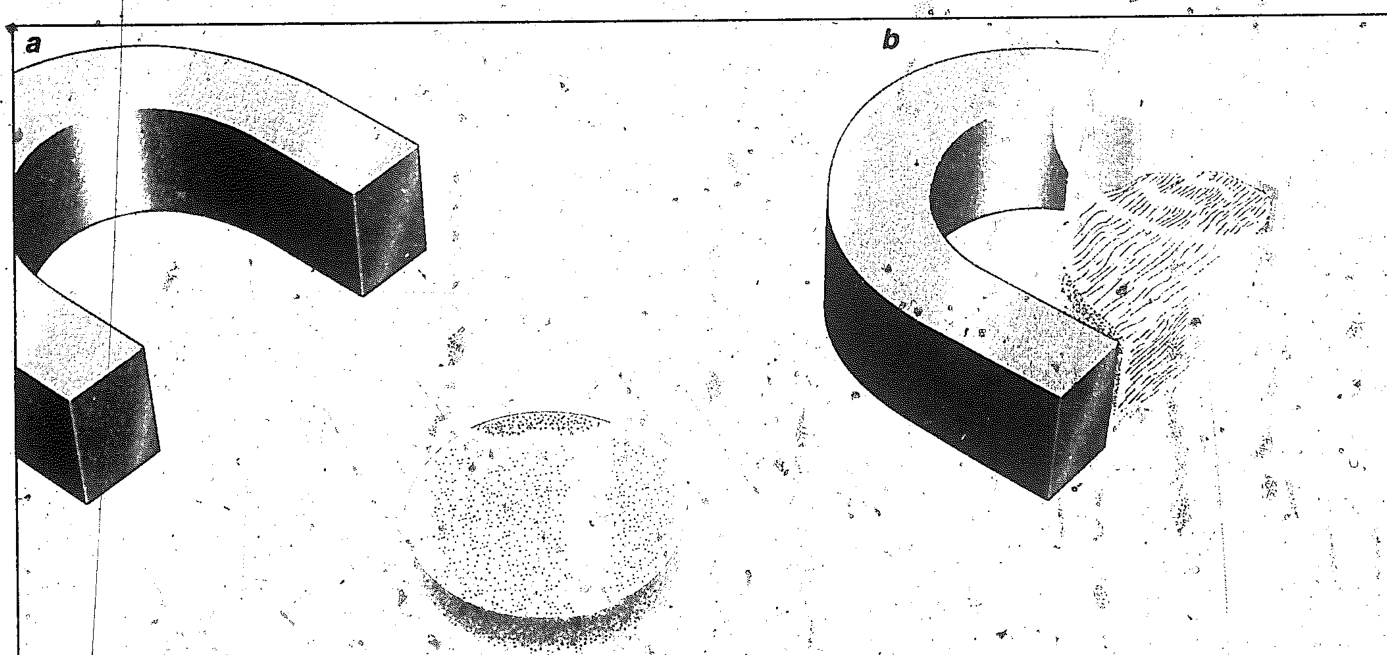


IRON FILINGS in corn oil produce a simple magnetorheological fluid. The mixture remains liquid (a) until a magnet is brought close to it. The filings line up between the poles, forming stiff, stringy masses that can be pushed to one side of the container (b). The material reverts back to its original liquid state once the magnetic field is removed.

work: horseshoes, bars, even the ones from old loudspeakers. (Refrigerator magnets are typically far too weak.) Magnets are often rated by the number of pounds they can pull. You should buy the most powerful ones available. I purchased two "100 pound" bar magnets from a local hardware store for about $12 apiece.

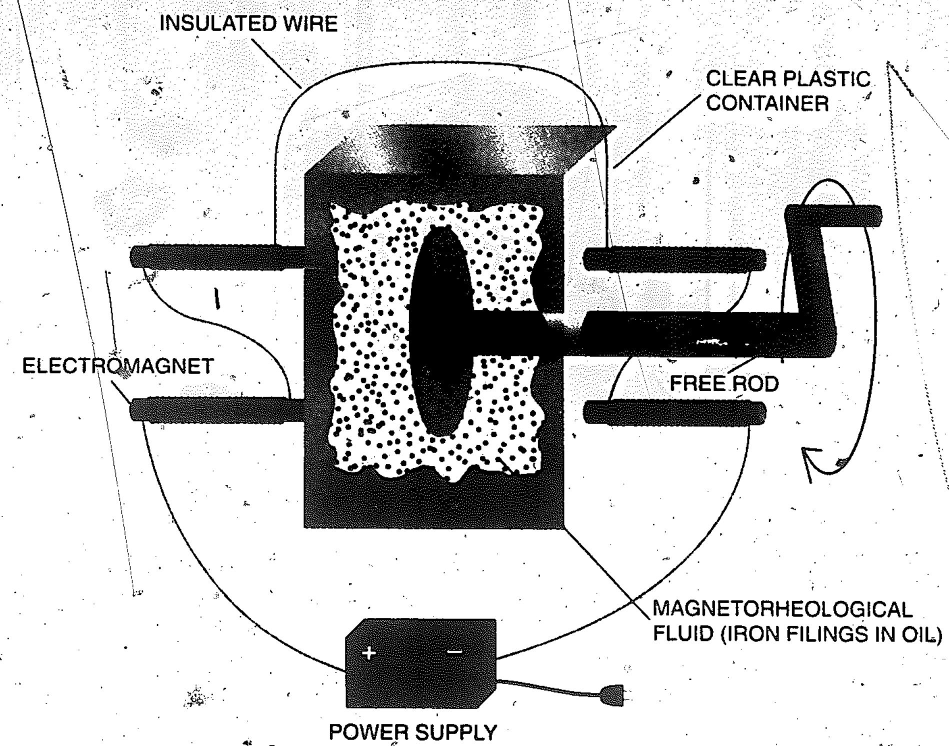
Electromagnets are also an option. Such magnets are made by winding thin, insulated wire around a metal bar and connecting the ends of the wire to a battery. The magnetic field will be strongest near the ends of the coiled wire. It does not matter whether you wind the wire from one end to the other or back and forth several times. Just be sure that the wire is always wound in the same direction (that is, clockwise or counterclockwise) and that the winding is tight. Two layers of windings over a couple of inches of the core should suffice.

To amplify the strength of the magnetic field, you can increase the power supplied to the electromagnet by connecting several batteries in series. Note, however, that the electromagnet draws a lot of current and will quickly drain the batteries. A power supply that can deliver several volts may be a better choice. Although it is quite fun trying to create a good electromagnet, it is hard to beat a permanent magnet in terms of both time and convenience if your goal is to play with a magnetorheological fluid.

Once you have your fluid and magnet ready, you can observe magnetorheology. First, stir the fluid with a piece of wood or plastic (the filings will adhere to a magnetizable object), keeping the magnet at least six inches from the container. You should notice that the combination of filings and oil behaves as a fluid: it continues to fill the container and tends to form a smooth, flat surface after you stop stirring. It has the consistency of maple syrup.

Bring the magnet near the container. If you are using a horseshoe-shaped magnet, put the container just inside the two legs. If you have two magnets, place the opposite poles on either side of the container, facing each other. The closer the poles are, the stronger the magnetic field in the fluid will be. If you have just one magnet, place one of the poles directly on the side of the container.

Stir the fluid again and notice how it begins to behave like wet sand. Distinct, stringy clumps should form at the bottom of the container. These clumps should retain their shape and remain suspended in the fluid after you remove the stirrer. The clumps appear stringy because the filings tend to attach end to end to one another, extending from the poles of the magnet. Now move the container away from the magnet. The filings-and-oil mixture will rapidly change back into a fluid: the clumps fall apart, and the surface becomes fairly smooth and horizontal. If you do not observe the effects, you probably either need to get a stronger magnet or need to change the consistency of the fluid.



MAGNETORHEOLOGICAL BRAKE relies on a disk mounted on a rod. Turning on the magnetic field prevents the rod from rotating. Batteries rather than a plug-in power supply can be used, although they will be drained quickly.

As a variation, repeat this experiment with different proportions of the filings and oil. The optimum combination will depend on the size of the filings and the type of oil. Also, attempt to vary the distance between the poles of the magnet and the container or else use a stronger magnet.

A much more challenging project is to create a simple magnetorheological brake [*see illustration above*]. Machining skills may be needed here. Insert the end of a rod into a plastic container filled with the magnetorheological fluid. The rod should be made of something that cannot be magnetized, such as plastic or aluminum. You might try attaching a plastic disk to the end of the rod in the fluid, because a larger surface area in the fluid will yield a more pronounced effect. To keep the fluid from leaking out, you may need to place a rubber O-ring around the rod where it enters the container.

Now all you need to do is immerse the container in a magnetic field. If you use electromagnets, I suggest wiring several perpendicular to the disk in the fluid. Be sure to wind the wire around each core in the same direction.

Before the magnetic field is applied, the rod rotates with little or no resistance. (To make the rotation more visible, you may wish to bend the end of the rod or attach some kind of handle.) Applying the magnetic field solidifies the fluid. The rod is now difficult to turn.

As you may notice with this combination of iron filings and corn oil, such fluids often do not solidify robustly and tend to break down over time. Research in industry and academia has made significant progress in improving these fluids for applications. For example, the Lord Corporation, based in Cary, N.C., plans to market magnetorheological fluids that promise to use much less magnetic energy to function than the formulation described here. But several years will pass before these fluids will drive and stop our cars.

FURTHER READING

FERROHYDRODYNAMICS. R. E. Rosensweig. Cambridge University Press, 1985.

ELECTRORHEOLOGICAL FLUIDS: PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE. Edited by J. D. Carlson, A. F. Sprecher and H. Conrad. Technomic Publishing, Lancaster, Pa., 1990.