

The
Video
Encyclopedia
of
Physics
DemonstrationsTM

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DISC FOURTEEN

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C H A P T E R 3 1

V I S C O S I T Y

An object falling through the air subject to the acceleration of gravity is also subject to a drag force due to the viscosity of the air. This force, which opposes the motion, is dependent on the geometry of the falling object. Two pieces of paper, one flat and the other crumpled into a small ball, are released from rest simultaneously and allowed to fall to the floor, as shown in *Figure 1*. The ball of paper, having less air drag, gets to the floor first.



Figure 1

We all know that very light objects such as this piece of paper appear to fall slowly. But is the slow descent caused only by their light weight, or is there some other reason?

If we crumple the piece of paper into a tight ball and drop it next to a flat piece of paper, the difference is clear.

There is more air drag on the larger surface of the flat paper, slowing its descent.

Equipment

Several pieces of paper.

Three balls are dropped into a tall cylinder of glycerin and allowed to drop to the bottom of the cylinder, as illustrated in *Figure 1*. The balls quickly reach terminal velocity, due in part to the viscous drag of the glycerine on the balls.[†] The following balls are dropped, in order: glass, steel, and lead. Terminal velocity is low for the glass ball, and higher for the steel ball, which is more massive. The lead ball is so massive that terminal velocity is not reached until the ball has dropped more than halfway down the tube.



Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Fm-1, Terminal Velocity.

Have you noticed that objects tend to move more slowly through a viscous liquid such as glycerine?

We'll drop various balls into this tube of glycerine to see how quickly they sink to the bottom.

For comparison here is how a glass ball falls in air.

Here is the same ball falling in a tube filled with glycerine.

It falls much more slowly.

Here is a heavier steel ball falling in glycerine.

Here is a still heavier lead ball falling in glycerine.

Here are all three balls falling side-by-side.

Equipment

1. Tall glass cylinder of glycerine.
2. Glass ball.
3. Steel ball.
4. Lead ball.

This demonstration is designed to extract measurements of acceleration of gravity and drag coefficient by analysis of data on the disc.

Six balls of various radius and density are dropped sequentially from a height of about 4 meters, as shown in *Figure 1*. By extracting from the disc the position versus time for each ball, the acceleration of the ball as a function of time can be determined. From the heavy balls the acceleration of gravity can be obtained and from the light balls the drag coefficient for the ball in air can be determined. The masses and the radii of the dropped balls, in order on the video, are:

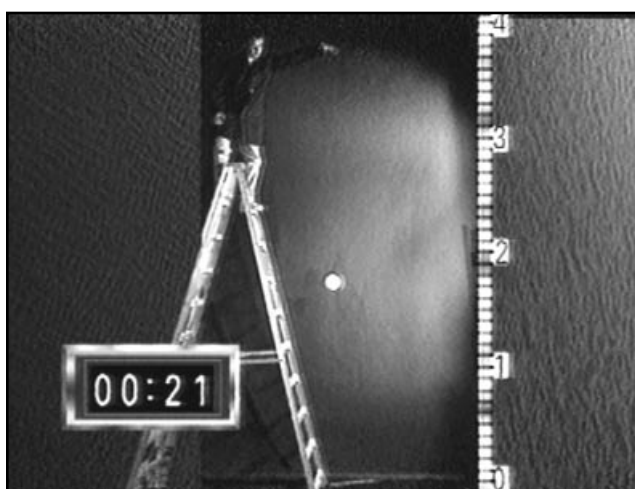


Figure 1

Superball	$m = 51.6\text{g}$	$r = 2.3\text{cm}$
Wooden ball	$m = 24.7\text{g}$	$r = 2.1\text{cm}$
Practice golf ball	$m = 8.3\text{g}$	$r = 2.1\text{cm}$
Small styrofoam ball	$m = 1.6\text{g}$	$r = 2.3\text{cm}$
Medium styrofoam ball	$m = 5.7\text{g}$	$r = 3.6\text{cm}$
Large styrofoam ball	$m = 30.3\text{g}$	$r = 6.3\text{cm}$

Elapsed time for each drop, in seconds and frames (one frame is one-thirtieth of a second), can be obtained from the clock at the lower left of the screen. Note that the clock is started before the ball is dropped in each case. The length scale can be obtained from the rule at the right, where the rule is marked in ten-centimeter units.

The equation giving the acceleration of the ball in a gravitational field in the presence of viscous forces is:

$$a = g - \left(\frac{b}{m}\right)v|v| \quad (1)$$

(1) where a is the acceleration of the ball, g is the acceleration of gravity, m is the mass of the ball, v is the velocity as a function of time, and the viscous drag

$$b = \left(\frac{1}{2}\right)C_D\rho A \quad (2)$$

where C_D is the drag coefficient for air, ρ is the density of air, and A is the cross sectional area of the ball.[†]

[†] Halliday and Resnick, *Fundamentals of Physics*, Volume I, pages 391-392, discusses this problem and gives mathematical details.

After first determining the acceleration of the ball, the viscous force coefficient can be obtained from equation (1) above and the drag coefficient from equation (2). Note that the velocity of the balls after about five centimeters of drop is about one meter per second, corresponding to a Reynolds number of about 7000, well above the domain in which the drag force is linear with velocity.

Ball Drop / Script**Demo 14-03**

Six balls will be released from rest from the same horizontal level and their position recorded as they fall using a fast shutter.

The mass and radius of each ball will be given just before it's dropped. In order, a superball.

A wooden ball.

A practice golf ball.

And three styrofoam balls of increasing size.

For taking data, position can be obtained from the 10-centimeter markings at the side of the picture. Time will be given in the lower left corner in seconds and frames; here one frame is one-thirtieth of a second.

Equipment

1. Tall ladder.
2. Superball.
3. Wood ball
4. Practice golf ball.
5. Three Styrofoam balls of varying diameters.
6. Two-meter stick.
7. Stopclock.

Gas from a tank feeds two identical burners through a T-tube. The gas in one arm of the tube is heated as shown in *Figure 1*. The heated gas has a greater viscosity, resulting in a smaller flame on the side with the heated gas, as can be seen.[†]



Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Fm-4, Dependence of Viscosity on Temperature.

When the temperature of a gas rises, its viscosity changes. We'll use this double gas burner to demonstrate the change.

The gas is turned on and both burners are lit. With both arms at the same temperature, the flames are of equal height.

Now we'll heat the gas in one of the arms with another burner. As the temperature of the gas rises in that arm, what will happen to the size of the flame?

The flame gets smaller. The viscosity of the gas has increased with rising temperature.

Equipment

1. Double burner "T" made of copper tubing with each end of the horizontal piece turned vertically upward.
2. Support system.
3. Supply of natural gas.
4. Source of flame.
5. Separate Meker burner.
6. Two lengths of rubber tubing.

At low temperature the viscosity of alcohol increases substantially. In this video, alcohol at room temperature is poured onto a cloth screen and immediately runs through the screen. When the alcohol is cooled to near the temperature of liquid nitrogen, it becomes very viscous. Alcohol near the temperature of liquid nitrogen poured onto the cloth screen flows slowly through the mesh of the screen due to its high viscosity.[†]

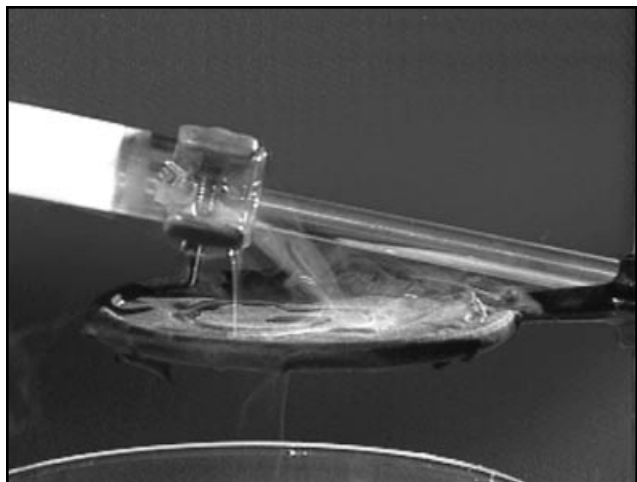


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Hk-10, Viscous Alcohol.

Alcohol is very non-viscous at room temperature, and flows freely.

When cooled to the temperature of liquid nitrogen, the alcohol becomes very viscous and will hardly flow at all.

Equipment

1. Supply of alcohol.
2. Ring stand supporting a ring clamp covered with cloth.
3. Catch basin of appropriate size.
4. Ring stand, test tube clamp, and test tube located at the height appropriate for the dewar.
5. Dewar of liquid nitrogen.

This video demonstrates the difference in viscosity between three weights of motor oil. Tubes filled with the oil, with a small bubble on top, are quickly inverted.[†] The bubbles begin to rise, with the bubble in the least viscous oil rising most rapidly, as seen in *Figure 1*.

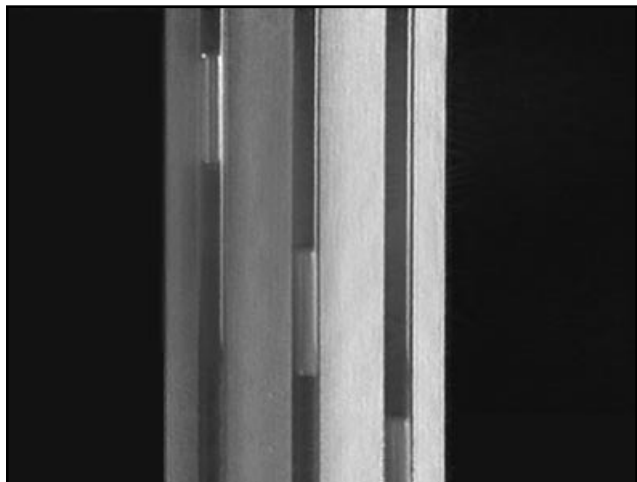


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Fm-2, Viscosity of Oil.

These three tubes contain motor oil with three different viscosities.

A small air bubble is at the top of each tube. When we turn the tubes over, the viscosity difference is apparent from the speeds at which the air bubbles move in each tube.

Equipment

1. Three longish glass tubes, each containing an oil of differing viscosity and sealed, leaving an air bubble of equal size in each.
2. Support system for glass that holds them vertically, then permits a quick and easy inversion.

C H A P T E R 3 2

T H E R M A L
P H E N O M E N A

Demo 14-07 **Thermal Expansion of Wire**

A wire is tightly stretched horizontally between two points. When an electrical current is passed through the wire, it is heated due to the I^2R losses. The wire expands and sags, as seen in *Figure 1*.

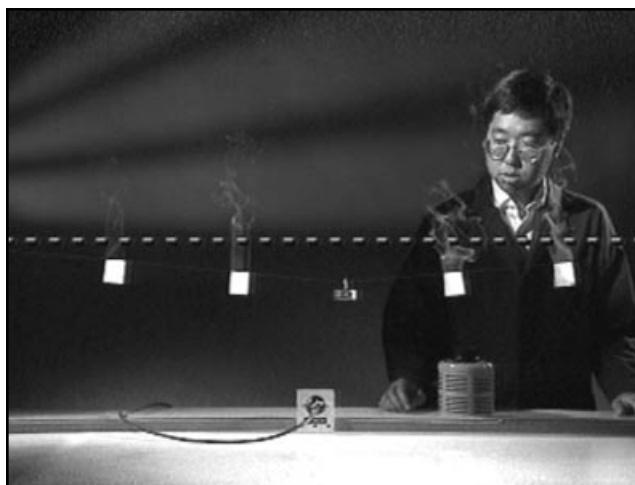


Figure 1

We'll use this long iron wire to show how materials expand when they are heated. A weight is hung on the wire, and an electrical current is run through the wire to heat it.

As the wire heats up, it expands and begins to sag.

Increasing the temperature increases the amount of expansion.

When the current is turned off and the wire cools, it contracts to its original length.

Equipment

1. Long iron wire tautly suspended on a wooden framework and wired and insulated for safe electrical conduction.
2. Small hooked weight.
3. Height indicator, perhaps a ring stand with a pointer rod and clamp.
4. Paper flags aid visibility for both elevation and temperature.
5. Variac.

A bimetallic strip consists of thin plates of two metals with different expansion coefficients rigidly connected along their length such that at normal room temperature the strip is straight. If the strip is heated or cooled, the difference in expansion of the two metals causes the bimetal strip to bend, as seen in *Figure 1*.[†] After heating the bimetal strip with a burner, it is cooled in liquid nitrogen so that it bends the opposite direction. A bimetal strip in the form of a helix, also shown on the video, is used to turn a pointer, indicating temperature.



Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-21, Differential Expansion.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ha-5, Bimetallic Strip.

This strip is made of two different metals with different coefficients of thermal expansion. If we put it in a flame, the strip bends.

What will happen when we put the strip in liquid nitrogen?

The strip bends the other way.

This animation shows an exaggerated view of the different expansion of the separate metals as they are heated. When they are bonded together, the difference in expansions makes the strip curve.

If this material is bent into a helix, heating the strip makes the helix twist further, turning a pointer which can be used to indicate temperature.

Equipment

1. Bimetallic strip.
2. Meker burner.
3. Length of rubber tubing.
4. Source of flame.
5. Dewar of liquid nitrogen.
6. Bimetallic coil with a pointer.
7. Hotel pad to help protect the table top.

A bimetallic strip can be used as a type of thermostat.[†] In this video the thermostat is arranged so that when it is cool it makes electrical contact and turns on a light, which heats the bimetallic strip, turning off the light and starting the cycle over. The apparatus is shown in *Figure 1*.

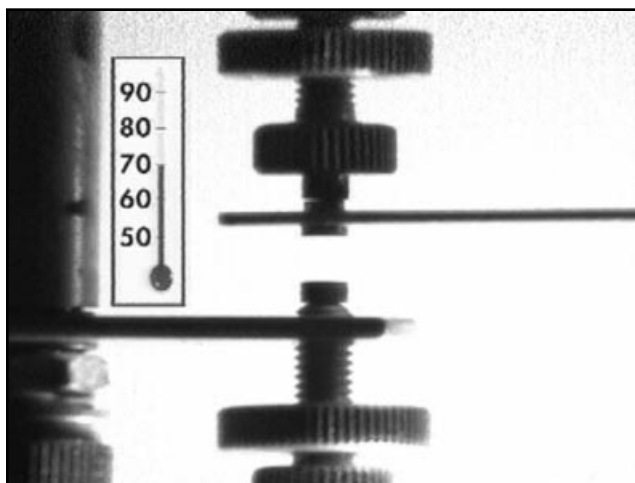


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-22.

When two metals with different expansion coefficients are joined together, the combination strip will bend when heated.

That property is used in a practical way in the design of a thermostat.

The bimetallic strip at the top of the model makes electrical contact with an adjustable screw. That contact provides power to a light.

As the light heats the bimetallic strip, it bends away from the screw, breaking the electrical contact and turning off the light.

When the strip cools, it straightens and remakes the contact, the light comes back on, and the cycle repeats.

The temperature of the thermostat is thus kept within a narrow range.

Equipment

1. Bimetallic strip.
2. Meker burner.
3. Length of rubber tubing.
4. Source of natural gas.
5. Source of flame.
6. Bimetallic strip-type thermostat model, complete with switch and light bulb.

A “pin breaker” uses thermal expansion of a long rod to break a one-eighth-inch diameter steel pin.[†] The pin has been inserted through the rod and tightened against a frame, as shown in *Figure 1*. As the rod is heated it expands, pushing the pin against the plate and ultimately breaking the pin.

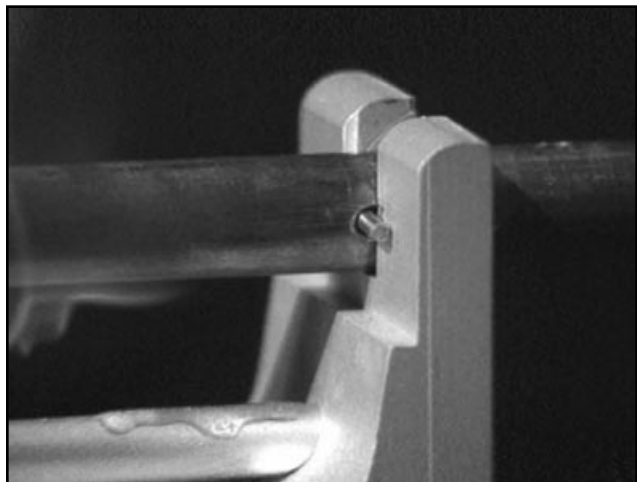


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ha-10, Forces Caused by Change of Length.

Almost all metals expand when they are heated. We'll demonstrate the immense force of that expansion using this iron rod and a steel pin.

The rod is placed in a strong frame, and the pin is put in a hole near the end of the rod. The pin is tightened against the frame by turning this large nut.

The steel pin is now pressed tight against the frame.

A series of gas jets under the iron rod are lighted and begin heating the rod.

After a few minutes of heating, the expansion of the rod breaks the steel pin.

This type of expansion would destroy bridges and other large metal structures, so they are designed with expansion joints that allow the metal to expand and contract without stress.

Equipment

1. Iron rod, threaded on one end with a hole to accommodate a steel pin through the other end.
2. Very strong supporting framework, complete with a burner tube running parallel and just below the iron rod's position.
3. Supply of quenched steel pins.
4. Pair of large locking nuts for the rod so the combination of the nuts and steel pin securely locks the rod into the framework.
5. Length of rubber tubing.
6. Supply of natural gas.
7. Source of flame.
8. Small mallet.

Demo 14-11

Thermal Expansion

This demonstration uses a variation of the classical ball and ring demonstration.[†] A metal plate with a circular hole, shown in *Figure 1*, is heated. A ball that initially cannot pass through the hole can pass through after the hole is heated. On the video the question is asked whether the hole becomes bigger, becomes smaller, or remains the same size when the plate is heated. The disc then stops to allow discussion of the question, and can be restarted when the discussion is complete. One perhaps counterintuitive issue is whether the metal around the hole “expands inward.”

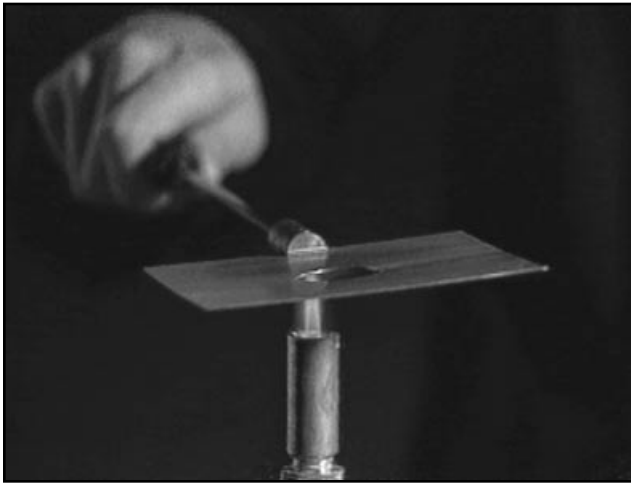


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ha-7, Ball and Ring.

Brass expands when heated. This thin brass plate has a circular hole in its center. When the plate is heated, will the brass expand inward? Will the hole become bigger, become smaller, or remain the same size?

To verify our result we compare the size of the hole with the size of this ball, which will not quite fit through the hole.

We now heat the plate.

After the plate is heated, the ball fits through the hole, indicating that the hole expands when the plate is heated.

Equipment

1. Piece of square brass plate with a center hole and handle off one edge.
2. Supply of natural gas.
3. Source of flame.
4. Brass sphere whose diameter is slightly larger than that of the hole in the brass plate which is also attached to a handle.

Demo 14-12 **Thermal Expansion of Air**

Two flasks are connected by a tube partially filled with colored water, as shown in *Figure 1*. When the air in the upper flask is heated by grasping it with warm hands, it expands and pushes the water down the tube into the lower flask.[†] This demonstration shows that air expands as it is heated. The temperature increase of the air in the upper flask has pushed the water level below the original marker.

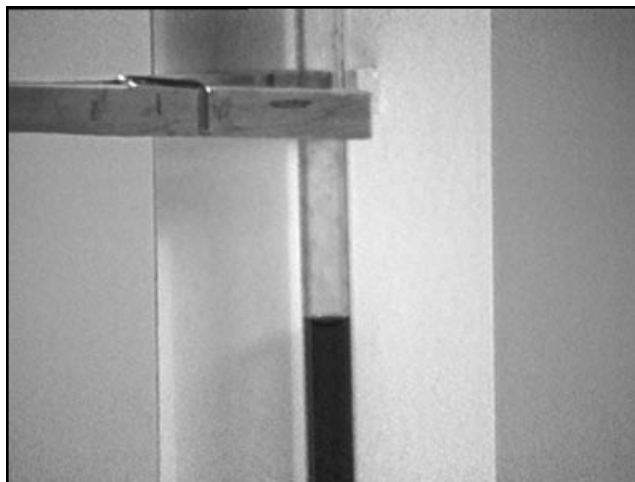


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ha-2, Gas Thermometer.

This is a model of the first crude thermometer designed by Galileo. A glass bulb at the top contains air at about atmospheric pressure. A tube runs down from the air flask into another flask filled with water, which has risen partly up the tube.

If a person places their hands on the air flask, the air expands and forces the water level in the tube down.

The water level thus gives a rough indication of the temperature of the air in the bulb.

Equipment

1. A Galilean air thermometer.
2. Support system for the glass assembly.
3. Clothes pin as water column height indicator.

Demo 14-13 Thermal Expansion of Water

A beaker is completely filled with water (no air) such that the water partially fills a small tube extending from the top end of the beaker, as shown in *Figure 1*.[†] The water is heated by a flame. As the temperature of the water increases from room temperature it expands, and the column of water in the tube above the flask rises higher, as seen in *Figure 1*. This demonstrates the basic concept behind the liquid-filled thermometer.

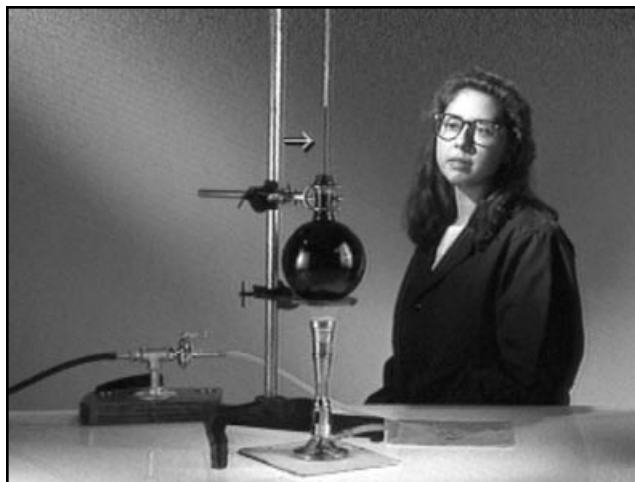


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-28, Expansion and Maximum Density of Water.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ha-9, Expansion of a Fluid by Heating.

We'll use this flask filled with colored water and fitted with a glass tube to demonstrate how a thermometer works.

When we heat the water in the flask, it expands and rises up the glass tube. The position of the water level can thus be used as an indication of the temperature of the water.

Equipment

1. Water thermometer fabricated by completely filling a round bottom flask with colored water and fitting it with a straight manometer tube.
2. Support system for glassware.
3. Meker burner.
4. Length of rubber tubing.
5. Supply of natural gas.
6. Source of flame.

Demo 14-14

Negative Expansion Coefficient of Water

A Pyrex beaker, which has a coefficient of thermal expansion much less than that of water, is completely filled with water at 0°C , with a column of water extending into a glass tube connected to the top of the beaker, as in *Figure 1*. As the temperature of the water increases, the height of the water column decreases until about 4°C , and then begins to rise again.[†] This demonstration illustrates that the density of water is the greatest at 4°C .

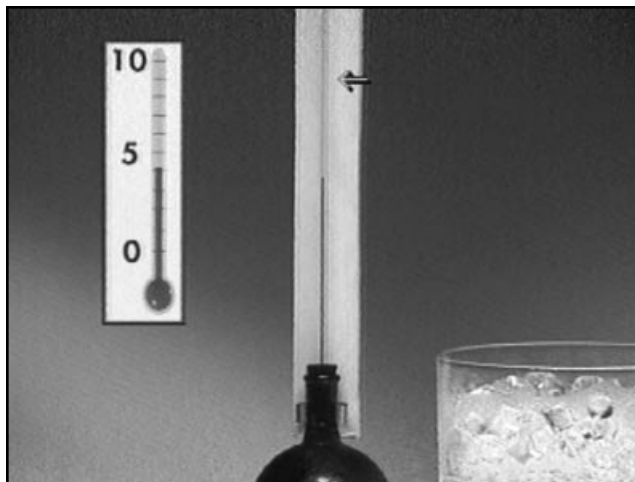


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstrations H-28, Expansion and Maximum Density of Water, and H-29.

Most liquids expand as their temperature increases. But there is one notable exception to the rule—water at low temperature. We'll use this flask filled with colored water and an ice bath to demonstrate how water can actually contract as it warms.

After about an hour in the ice bath, the water inside the flask is nearly at zero degrees celsius.

The flask is now removed from the ice.

We'll follow the water level in this capillary tube using time-lapse photography as the water temperature increases.

The water level drops at first. The water is contracting as the temperature increases.

When the temperature of the water reaches four degrees, normal expansion begins.

Equipment

1. Water thermometer (as discussed in Demonstration 14-13) using a manometer tube with small inside diameter.
2. Sizable ice bath.
3. Thermometer.
4. Cradle for the flask when it is removed from ice bath.

This demonstration illustrates a dust explosion, in which small particles of a normally stable material become highly explosive. A pile of lycopodium powder will not burn. However, if this powder is blown into a cloud, the surface area of powder that contacts the oxygen in the air is vastly increased, and the powder will rapidly burn if it comes in proximity of a flame. About one tablespoon of powder is blown out of a funnel, forming a cloud that ignites when it reaches a burning candle about one foot above the funnel, as seen in *Figure 1*.



Figure 1

Lycopodium powder will not burn if it is exposed in bulk to a flame. What happens if we form an airborne dust in which the particles of lycopodium powder are surrounded by air and exposed to a flame?

About a tablespoon of lycopodium powder is placed in this funnel and a candle about 30 centimeters above the funnel is lit.

A cloud of powder is created by blowing into a rubber tube attached to the bottom of the funnel.

Equipment

1. Supply of lycopodium powder.
2. Source of flame.
3. Glass funnel clamped upright to a ring stand, with a long length of rubber tubing attached to its stem.
4. Candle clamped several inches above the funnel's mouth.
5. Appropriate safety gear.

This demonstration illustrates how the ratio of surface area to volume is increased when an object is broken into small pieces. This is the effect that allows the lycopodium powder of Demonstration 14-15 to become highly combustible. A cube formed from a large number of smaller cubes has its outside surface painted. When the cube is broken down into a large number of smaller cubes its volume remains the same but its total surface area is much larger, as can be seen by comparing the painted and unpainted surfaces of *Figure 1*.



Figure 1

This wood cube will be used to demonstrate how the ratio of surface area to volume changes as objects become smaller. The cube has been cut into twenty-seven smaller cubes, and the outer surface of the larger cube has been painted black.

If we take the cube apart, the total surface area of the cubes increases.

The original surface area, painted black, is still there. But the unpainted portions of the cubes are new surface area, which has been added to it. The volume of the cubes has not changed, but the surface area has greatly increased.

Equipment

Twenty-seven small cubes stacked up into a larger cube—3 units by 3 units by 3 units. All of the outer surface area of the larger cube is painted black.

Demo 14-17 Specific Heat

This demonstration compares the specific heat of three materials: aluminum, steel, and lead. Equal masses of these three materials are heated to 100°C and placed into identical cool water baths.[†] The temperature rise of the water bath is a function of the specific heat of the hot metal added to the water; the greater the specific heat, the greater the temperature rise in the water bath. The temperature rise is measured using an LED bar graph, as shown in *Figure 1*. The specific heat is lowest for lead and greatest for aluminum.

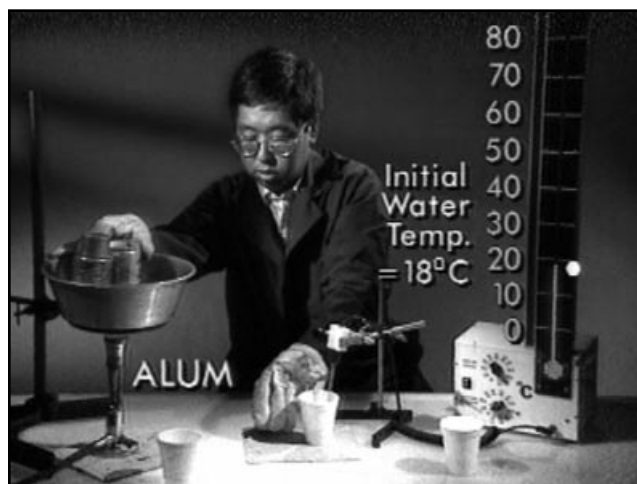


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-40.

Different metals have different specific heats. We'll demonstrate that using equal masses of lead, aluminum, and steel shot.

Seventy-five grams of each metal are placed inside soda cans that are sealed and put into boiling water.

When the metal samples reach 100 degrees celsius, we'll pour each of them into 50 grams of water and measure the increase in temperature of the water.

The lead sample increases the water temperature 4 degrees celsius.

The aluminum sample increases the water temperature 14 degrees celsius.

The steel sample increases the water temperature 8 degrees celsius.

Aluminum has the highest heat capacity of the three metals and lead the lowest.

Equipment

1. 75 grams of lead shot.
2. 75 grams of aluminum chips.
3. 75 grams of steel shot.
4. Three aluminum soda cans with lids.
5. Boiling water bath large enough to hold all three cans.
6. Support system for bath.
7. Meker burner.
8. Length of rubber tubing.
9. Supply of natural gas.
10. Source of flame.
11. Three Styrofoam cups.
12. Sensitive thermometer.
13. Support system for thermometer in the Styrofoam cup.

Demo 14-18

Specific Heat with Rods and Wax

The specific heats of three metals, aluminum, steel, and lead, are compared by allowing equal masses of hot rods of the metals to melt wax, as illustrated in *Figure 1*.[†] The metal rods melt through the wax, and the rod with the highest specific heat melts further through the wax before cooling sufficiently that further melting ceases. In order from left to right in the Figure are aluminum, steel, and lead.

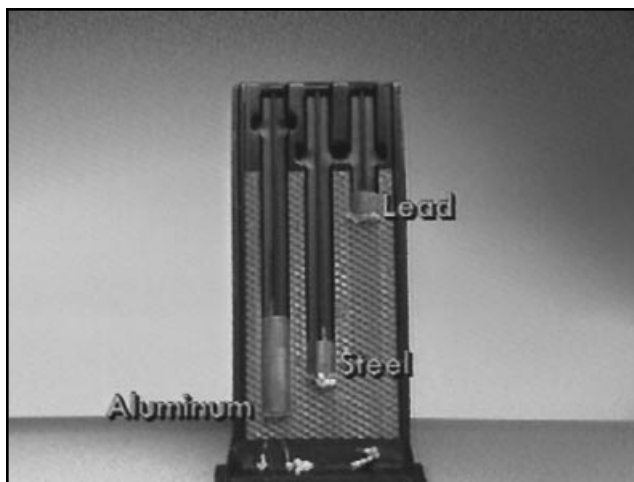


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-36.

We'll use these three metal cylinders to demonstrate how heat capacity varies for materials.

The cylinders, made of aluminum, steel, and lead, have equal mass. They are slotted to slide on small rails in this frame, which is covered with a thin sheet of beeswax.

The rods are heated in boiling water to 100 degrees celsius.

When placed on the rails above the wax, they begin to melt their way down through the sheet.

Aluminum, with the highest heat capacity of the three, travels farthest, followed by steel, then lead.

Equipment

1. Three cylinders of aluminum, steel, and lead having equal mass and equal diameters.
2. Slanted and slotted guide covered with a thin slab of beeswax.
3. Boiling water bath and its support system.
4. Meker burner.
5. Length of rubber tubing.
6. Supply of natural gas.
7. Source of flame.
8. Sizable pair of tweezers.
9. Pair of gloves.

Demo 14-19 **Boiling Water in a Paper Cup**

Water can be boiled in a paper cup! Because the kindling point of the paper is a higher temperature than the boiling point of the water, the water bath, as seen in *Figure 1*, keeps the cup at a temperature sufficiently low that it will not burn.

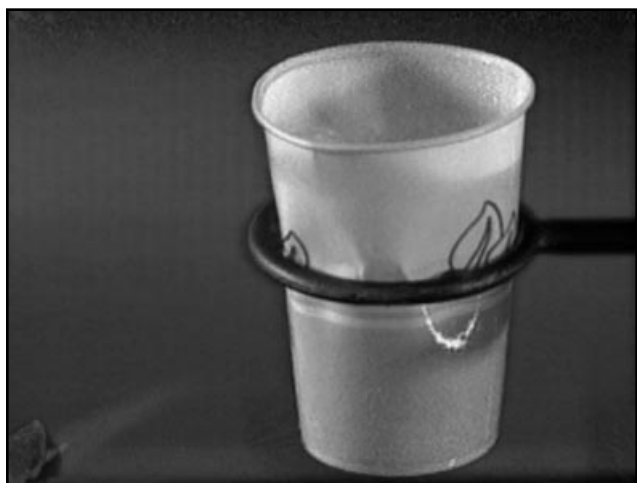


Figure 1

When we touch this paper cup with the flame from a torch, it quickly catches fire.

When we fill an identical cup with water and bring the flame up again, the cup withstands the flame without harm.

The flame can play onto the cup long enough to boil the water inside without burning up the cup.

Equipment

1. Supply of paper cups.
2. Ring stand.
3. Ring clamp of appropriate size.
4. Supply of water.
5. Source of hot flame.

If a flame is applied to a balloon filled with air, the balloon will heat up sufficiently to rupture. If the balloon is filled with water, the large heat capacity of the water keeps the rubber of the balloon cooled sufficiently that it will not be damaged, as seen in *Figure 1*.

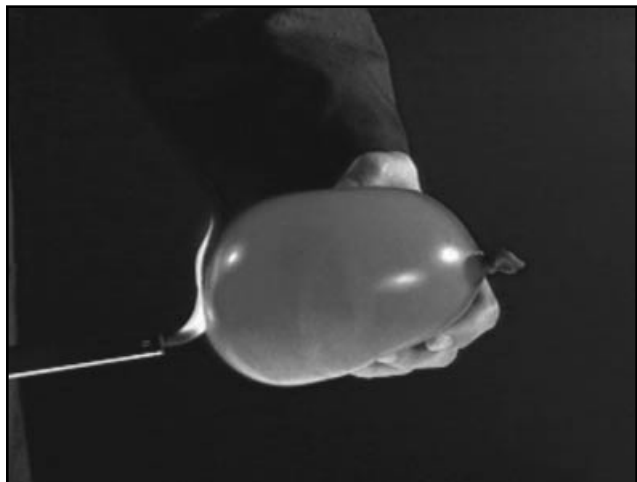


Figure 1

When we put a flame to this balloon filled with air, the balloon explodes.

But an identical balloon filled with water easily withstands the flame. The high heat capacity of the water allows the balloon to absorb large amounts of heat without a large rise in temperature.

Equipment

1. Supply of balloons.
2. Source of flame.
3. Supply of water.

C H A P T E R 3 3

H E A T T R A N S F E R

Demo 14-21

Thermal Conductivity

Rods of various materials extend outward from a heat sink that is heated up to 100°C and maintained at that temperature. The rods are coated with wax. As heat is conducted along the rods, the wax melts progressively outward on each rod, as shown in *Figure 1*, illustrating the ability of the material to conduct heat.[†] This demonstration compares the heat conductivity for the following materials and shows that the heat conductivities assume the following order, from lowest to highest (left to right in *Figure 1*): glass, steel, brass, aluminum, and copper.

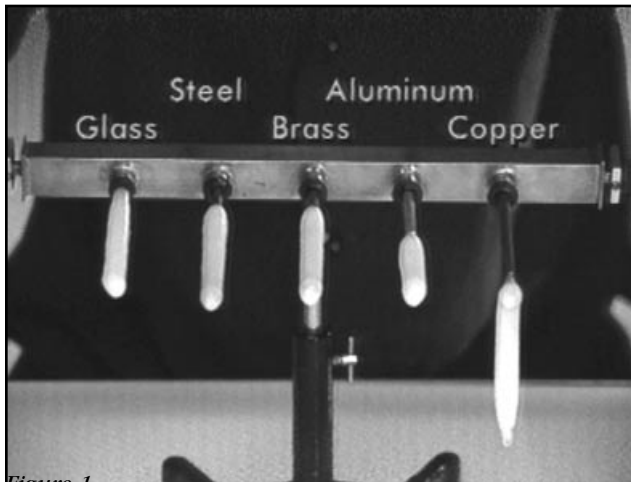


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Hd-1, Conduction of Heat.

We'll examine the thermal conductivity of different materials using this apparatus.

Five rods, made of glass, steel, brass, aluminum, copper, have been coated with a thin layer of wax. The rods are connected at their bases to this chamber.

Steam is passed through the chamber, heating the base of each rod to the same temperature.

The rate at which wax melts off each of the rods is an indication of the rate of heat transfer through that material.

We'll watch with time-lapse photography as the wax melts.

Equipment

1. Five identical rods of glass, steel, brass, aluminum, and copper extend out from a common steam reservoir, with each of the five having been equally dipped in molten paraffin.
2. Support system for the apparatus.
3. Two lengths of rubber tubing extending from either end of the steam reservoir.
4. Steam generator and its source of heat.
5. Sink.

When a drop of water is placed on a hot skillet, it does not immediately boil, but is insulated from the hot metal by a thin layer of steam, that forms between the water drop and the skillet. This phenomenon, illustrated in *Figure 1*, is known as the Leidenfrost phenomenon. Other variations include licking a hot metal rod, plunging your hand into molten lead, and walking on hot coals without shoes.[†] The video shows water on a hot skillet and liquid nitrogen on a table top.

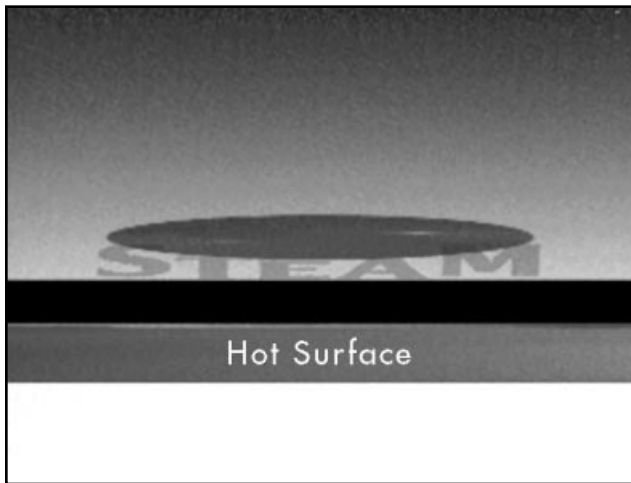


Figure 1

[†] Jearl Walker, *The Flying Circus of Physics, with Answers* (Wiley, New York, 1977) number 3.65, page 63.

Have you ever noticed that water on a very hot frying pan can last for a long time, even though the temperature of the pan is well above the boiling point of water?

The water actually boils instantly when it touches the frying pan, but that generates a layer of insulating steam between the water and the pan. The steam layer greatly reduces the heat transfer into the rest of the drop which can therefore last a long time.

Liquid nitrogen behaves in a similar fashion when poured onto a room temperature table.

Equipment

1. Stove or hot plate.
2. Skillet.
3. Source of water.
4. Supply of liquid nitrogen.

A radiometer consists of a set of four identical vanes, each black on one side and white on the other side, mounted on a low-friction suspension, as shown in *Figure 1*. When heat is radiated onto the radiometer vanes, the vanes rotate on the pivot such that the black side rotates away from the heat source, opposite to the sense of rotation “predicted” if the effect were due to the scattering and absorption of photons.[†] The full explanation of this demonstration is somewhat more complex than the standard discussion of heat absorption and molecular motion.[‡]

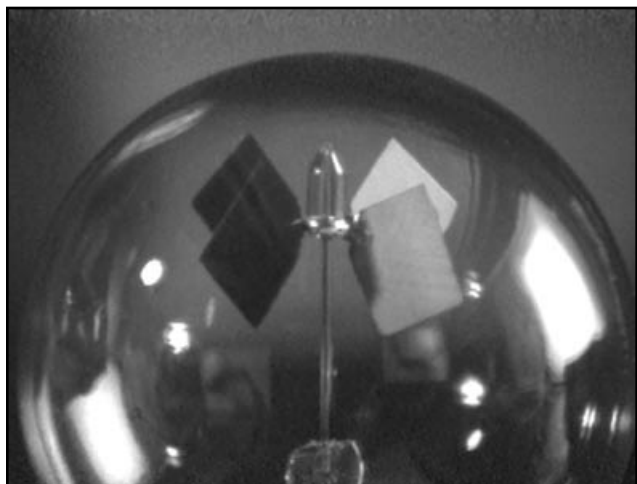


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-164, Crookes' Radiometer.

[‡] Arthur E. Woodruff, The Radiometer and how it does not work, *Phys.Teach.* 6, 358-363 (1968).

Here is a device known as a radiometer. It consists of an evacuated glass tube containing a set of four vanes free to rotate on a spindle. Each of the vanes has one white face and one dark face. When strong light strikes the radiometer it begins to spin, with the dark faces moving away from the light.

Equipment

1. Radiometer.
2. Lamp.

This demonstration illustrates the difference between thermal radiation properties of black and shiny cans.[†] The two cans are initially filled with cool water and allowed to absorb heat from a heat lamp as their temperatures are monitored using digital thermometers. Because a “blackbody” absorbs more efficiently, the black can heats up more quickly, as can be observed in the video. In the second part of the video the cans are filled with hot water and allowed to cool while their temperatures are monitored. The black can also radiates more efficiently, and thus cools faster, as shown in *Figure 1*.

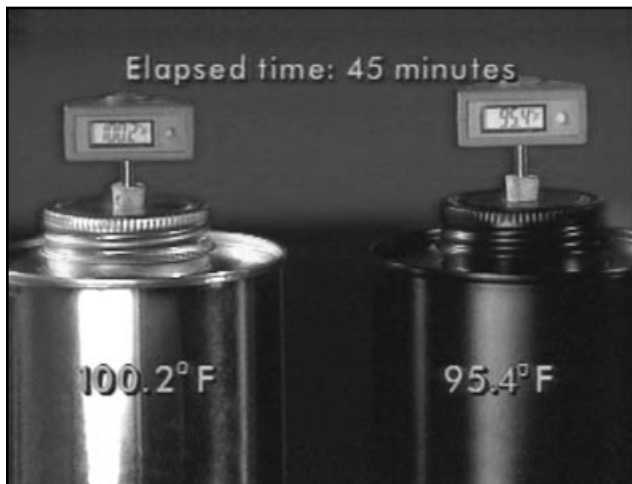


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstrations H-56, Surface Radiation, and H-159, Surface Absorption.

We'll place these two cans in front of a hot light, and watch how their temperature changes as they absorb heat from the lamp.

A few minutes later, the black can is much hotter than the shiny can because it has absorbed more thermal radiation. Now let's try the same demonstration in reverse. Both cans are filled with hot water and allowed to cool.

Which of the cans will cool faster?

The black can cools faster because it emits thermal radiation at a higher rate than does the shiny can.

Equipment

1. Two identical metal cans with caps, each with a hole; one painted flat black, the other shiny metal.
2. Two thermometers with corks to fit the holes in the can's lids.
3. Supply of hot water.

The radiation cube, or “Leslie Cube,” illustrates the difference between radiation from various surfaces at the same temperature.[†] The cube is filled with boiling water, and the radiation from each surface sensed with a thermopile as indicated in *Figure 1*. The radiation efficiency of several surfaces is noted in the video. The surfaces, in order of decreasing radiation efficiency, are flat black (2.0), shiny black (1.8), white (1.7), and shiny metal (0.2). The radiation efficiencies of the painted surfaces are similar despite their different colors., but the black painted surface radiates slightly more than the surface painted white. The shiny bare metal surface radiates heat at a much lower rate.

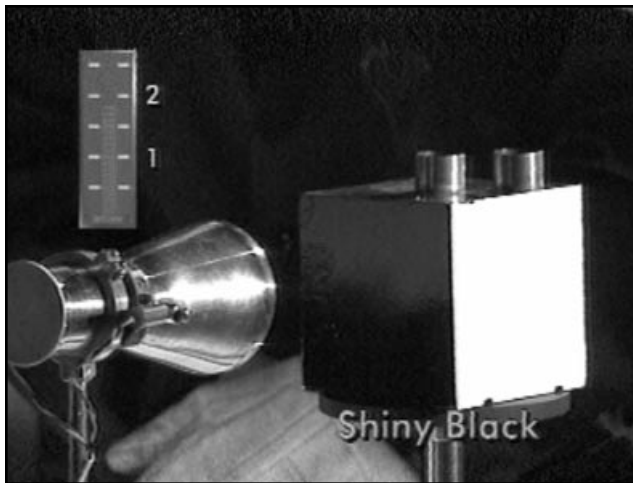


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstrations H-156, Surface Radiation, and H-161, Leslie Cube.

This metal cube has faces painted flat black, white, gloss black, and a fourth face that is bare metal. We'll use it to show how the emission of infrared energy compares for four different surfaces.

Hot water poured into the box heats each of the faces to the same temperature.

Is the infrared radiation emitted by all faces the same? We'll use this thermopile detector hooked to a galvanometer to find out.

Here's the amount of radiation from the bare metal face.

Here is the amount of radiation emitted from the flat black face.

Here's the amount of radiation from the white face.

Here's the amount of radiation from the shiny black face.

Equipment

1. Leslie cube.
2. Rotating support stand.
3. Supply of hot water.
4. Thermopile detector.
5. Galvanometer.
6. Pair of gloves.

This demonstration illustrates the effectiveness of various dewar flasks for keeping hot water hot.[†] Boiling water is placed into four flasks which are, respectively: silvered with good vacuum, unsilvered with good vacuum, silvered with poor vacuum, unsilvered with poor vacuum, from left to right in *Figure 1*. The video shows that the ability to keep the water hot, in order of decreasing efficiency from left to right, is (1) vacuum plus mirrors, (2) vacuum but no mirrors, (3) mirrors but no vacuum, and (4) neither vacuum nor mirrors.



Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-166, Dewar Flask.

This flask is used to keep hot liquids hot for long periods of time. We'll demonstrate how it works using these four Dewar flasks with different types of insulation.

Each flask actually consists of two flasks, one inside the other, with a gap in between. This flask has a vacuum between the inner and outer jars and a mirror coating on both inside surfaces.

This flask has a vacuum but no mirror coating.

This flask has a mirror coating but no vacuum.

This flask has neither a mirror coating nor a vacuum.

We'll put boiling water in each of the flasks so that they start at approximately the same temperature.

One hour later, the water temperature in the first flask has gone down only a few degrees, while the temperature drop in the other flasks is greater for each successive flask.

Equipment

1. Set of four dewar flasks with the following properties:
 - a) evacuated with dual mirror coating,
 - b) evacuated, but no mirror coating,
 - c) mirror coating, but no vacuum,
 - d) no mirror coating and no vacuum.
2. Rack to support the dewars.
3. Supply of boiling water.
4. Four thermometers with corks to fit the dewars.
5. Gloves.

This demonstration illustrates heat convection currents in water using projection of the convection currents by a projector.[†] An electric current is passed through a wire in the bottom of the water tank, creating heat convection currents that can be easily observed by projecting the plane of the action onto a screen, as shown in *Figure 1*. Downward convection currents are produced by putting a cold metal rod into the heated water.

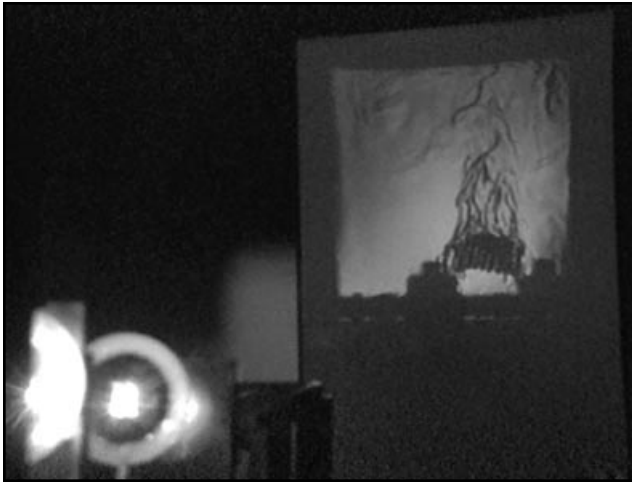


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration H-142.

You've probably seen the air shimmering above the ground on a hot afternoon. That shimmering is caused by convection currents in the air.

We'll use this projector to show similar convection currents in a small cell of water.

The glass cell has a small heater wire in the bottom, and is filled with water before being placed in the projector.

Here is the projected image of the cell on a screen.

As the wire is electrically heated, convection currents rise into the cooler water above.

If the wire is made hotter, the convection currents move more rapidly and become turbulent.

After the convection currents have heated the water, we can place a cold metal rod into the cell to create downward convection currents.

Equipment

1. Glass cell containing water with an electric heating coil near its bottom.
2. Support system for the glass cell and the Schlieren optics system used to project the convection currents.
3. Variac.
4. Cold metal rod to show the falling convection currents.