Low Priced, Low Tech Vacuum Demonstrations

- Appropriate for middle school science programs
- Low cost, easy to operate, difficult to break
- Materials available from science supply catalogs or hardware stores

Workshop Presented By
The Northern California Chapter
American Vacuum Society (NCCAVS)

www.nccavs.org

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Basic Apparatus

Vacuum Pump

Squeeze handle vacuum pump (Cynmar Corp.)
$10 (without gauge)
$20 with vacuum gauge

Hand Air/Vacuum Pump similar to bicycle tire pump, but can also be connected as a vacuum pump. No gauge. $20 – Cynmar Corp.

FoodSaver® electric vacuum pump, hand held model: $40. A similar black WineSaver pump with two bottle stoppers is $50. (www.foodsaver.com)

Standard FoodSaver pump. Black&Decker has similar pump. May be available at flea markets, etc.

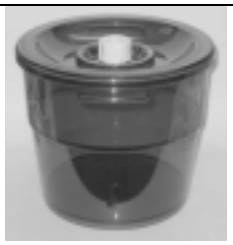
Note: The hand pumps sold for exhausting wine bottles or marinators are not recommended.

Only one vacuum pump is required. The electric hand held FoodSaver pump is the easiest to use. Under optimum conditions (no leaks) this FoodSaver pump can achieve a vacuum of less than 0.2 of an atmosphere (180 Torr or 240 mbar), equivalent to an altitude of 40,000 ft.

Vacuum Chamber

- FoodSaver® "Seal-A-Meal" canisters. Available at Target, K-Mart, etc.

Round Canisters – Set: $23.00
4" x 5 7/8" high
5" x 6.75" high
6" x 8" high



4 qt bulk storage canister: $18.00
8-1/8" × 7-3/8

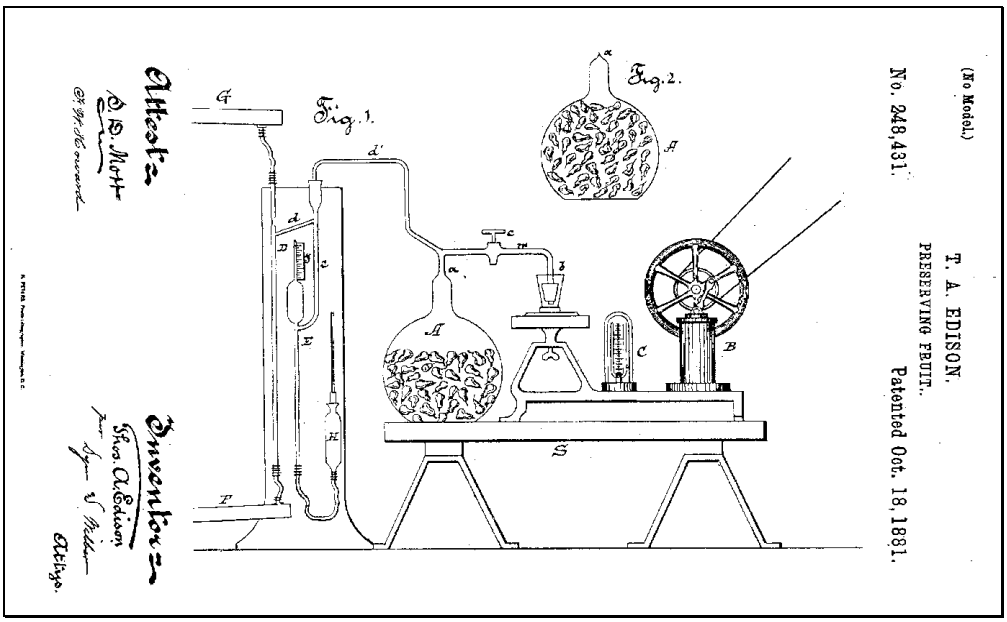
3 qt tall canister
~ 11" high

Square – no dimensions given
(2.25 qt.) – $22.00

8.75" long x 6.75" deep x 6.75" high (2 qt.) – $34.00

- Nalgene 5305-6609 polycarbonate vacuum chamber with baseplate: 6-5/8 × 9-3/8 inch– $80.
- Polyetherimide vacuum chambers 8¾×10 and 12×12. Nalgene vacuum chambers and baseplate. Available through distributors: Cynmar, Fisher Scientific, VWR, etc.
- Cynmar –Chamber and baseplate: $70.00; Baseplate only: $15.50.

Nalgene 12×12-inch vacuum chamber with baseplate.



Thomas Edison's 1881 "food saver" patent. Fig.1 shows use of a Sprengel mercury aspirator vacuum pump (at left) and a power-driven mechanical pump (B). Fig. 2 shows a flask containing fruit is sealed off after evacuation (A). The vacuum pumping system shown was developed for the mass production of Edison's incandescent electric lamp. (www.uspto.gov).

Vacuum Gauge

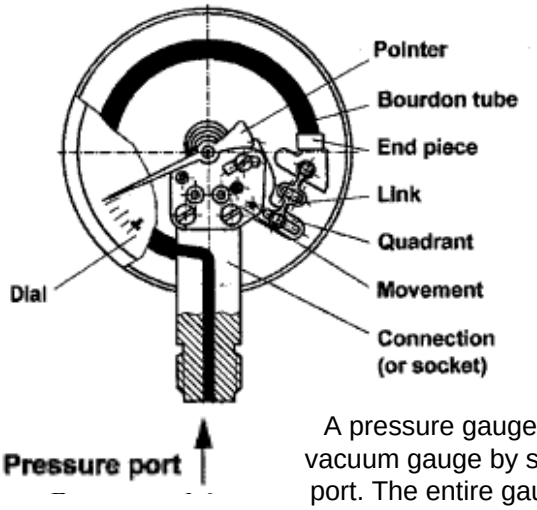
Automotive stores sell a vacuum gauge for bleeding brakes.

A 0-30 PSI (pounds/ square inch) gas test pressure gauge available at a plumbing supply area of a well-stocked hardware store can be modified to use as a vacuum gauge by sealing the inlet with a pipe threaded cap and Teflon® tape. The gauge is placed *inside* the vacuum chamber so that the dial is visible.

A pressure gauge used in this manner will read zero at atmospheric pressure. The vacuum pressure will be the seal-off pressure (assume 14.7 PSI) minus the gauge reading.

Immersed Gauge Reading (PSI)	Pressure			Approximate Altitude (feet)
	PSI	Torr (mm Hg)	mbar	
0	14.7	760	1010	0
2	12.7	660	880	4,000
4	10.7	550	740	8,500
6	8.7	450	600	14,000
8	6.7	340	460	21,500
10	4.7	240	320	29,000
11	3.7	190	255	34,000
12	2.7	140	190	40,000
14.7	<1	<100	<140	

Bourdon Pressure Gauge used as a Vacuum Gauge



A pressure gauge can be used as a vacuum gauge by sealing the pressure port. The entire gauge is placed in the vacuum chamber and the gauge body pumped to vacuum level.

Patented in France in 1849 by Eugene Bourdon.

Vacuum Gauge, Edmund Scientific– $13
A Bourdon-type dial vacuum gauge with a range of 0-30 inches Hg vacuum (approx. 0-760 Torr). 6-cm diameter black steel case with a ¼" NPT brass connection. Edmund also has heavy rubber tubing, brass connectors. (http://sciencekit.com, Search: vacuum).

Vacuum Valve

Gas shut-off valves, about $5-$6 at a plumbing or hardware store. Brass stem valves and plastic ball valves seem to work fairly well in the 25 to 10 Torr pressure range. The brass stem valves are stiff and need periodic greasing.

Vacuum Hose and Fittings

Flexible vinyl plastic tubing to connect from the vacuum pump to the vacuum chamber. Use thick-wall tubing, available at a hardware store plumbing department. Use with metal fittings and metal hose clamps.

Demonstrations Using FoodSaver Pump & Canisters

Force of Air Pressure

Apparatus

- Two metal or plastic half spheres (Magdeburg hemispheres) and the hand operated vacuum pump or FoodSaver pump.

Note: The Magdeburg hemispheres shown may need a better seal than provided. A thin flat rubber gasket works well. Lubricate well with petroleum jelly (Vaseline).
Cynmar Corp. (www.cynmar.com) – $9

The sphere opens easily with atmospheric pressure inside but when you pump down a properly sealed sphere, you can't pull them apart.

Problem: Calculate the total surface area of a 4-inch diameter sphere and the total force in pounds holding the hemispheres together.

Question: If air has so little density (see the mass of air experiment), why is atmospheric pressure so high? What causes wind?

The "standard" atmospheric pressure of 14.7 lb/square inch can also be dramatically demonstrated by lifting a vertical 1×1-inch steel bar that weighs 14.7 pounds. The length of the bar will be about 52-13/16 inches inches.

Does the Speed (Acceleration) of a Falling Object Depend on Weight?

Galileo is reported to have demonstrated this by dropping objects from the Tower of Pisa in 1613. About 1662 Christian Huygens performed the Feather and Guinea (a coin) experiment in a vacuum to eliminate the effect of air resistance.

Materials: A small magnet, iron washer, and very small feather (goose down is good) and a few *Bounce* (or equivalent) anti-static sheets.
Procedure:

- Drop the feather and washer from a height of about a foot to show they fall at different rates.
- Secure the coin with the tip of the feather under it to the underside of the lid of the tall canister with the magnet on the outside. Be sure that the feather is not stuck to the plastic by static attraction. SPECIAL HINT: Wipe the feather and the inside of the plastic canister with a new *Bounce* anti-static sheet beforehand.

- Place lid on canister and pump down.
- Pull magnet away to release coin.

NOTE: This experiment takes some practice. You may find it easier to place the feather/washer/magnet at the bottom of the canister rather than the lid, pump down, and then carefully invert.

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Strange Effects of a Vacuum

Things to expose to a vacuum:

- Small balloon (tied off and partially inflated) – Demonstrates Boyle's Law.

At atmosphere

Under vacuum

- Plastic bottle with cork in neck (what should happen? What does happen?)
- A pea-size dab of shaving gel (Use a small container, e.g. a 50 ml beaker or be prepared to clean the canister).
- Marshmallow "Peeps"

More details at www.nccavs.org, Educational Activities, download Strange Effects of a Vacuum PDF file.

Sources

FoodSaver® "Seal-A-Meal" canisters and pumps. Available at Target, K-Mart, etc. and Foodsaver.com

Cynmar Corp., www.cynmar.com

Edmund Scientific – http://sciencekit.com, Search: vacuum

Nalgene vacuum chambers and baseplates – www.nalgene.com

Gauges, valves, tubing – Duniway Stockroom, 1305 Space Park Way, Mountain View, CA 94043, www.duniway.com, Tel: 650-969-8811; 1-800-446-8811

Other Experiments and Demonstations

Is There Sound in a Vacuum?

Materials: FoodSaver canister, small travel alarm, rubber band, duct tape.

Procedure:

- Tape rubber band to lid and alarm clock as shown below.
- With alarm ringing, place lid on canister. Be sure that clock does not touch the canister.
- Pump with FoodSaver pump. Note: This is noisy.
- Stop pump when light goes on and remove.
- You will still hear the alarm, but note the loudness.
- Release the vacuum, the loudness of the alarm should increase perceptibly.

Rubber band taped to clock and inside of canister lid

Alarm clock suspended by rubber band.

Questions:

Why use a rubber band suspension?
Why can you still hear the sound in this “vacuum”?

Water Barometer

Apparatus

A closed container containing water, with a connection for a length of vinyl tubing.

There are elegant glass swan barometers with a closed body and opening in the beak. $10-$20. Fill with colored water.

A plastic or glass bottle with a plastic tube attached also works.

Compare the water level inside closed container (below a volume of trapped air) with the water level in the portion open to air.

If an inverted graduated cylinder is used, you have a built-in scale.

Demonstration That Air Has Mass

Apparatus

- Metal or rigid polycarbonate plastic vacuum container with a volume of at least 0.5 liter (500 cc or about 16 ounces volume) and a vacuum valve.
- A suitably sensitive balance scale. The density of air is about 1.3 mg/cm^3 so the weight change for a 500 cc container would be only about 0.65 g.

Experiments

- The vacuum container is weighed, the air is evacuated and the cylinder is weighed again.
- Weigh an uninflated balloon, inflate and weigh again. Explain the result of this experiment. Hint: Can you weigh a submerged water-filled balloon?

Plastic Tube Manometer

Apparatus

A manometer can be constructed using 3/8" ID flexible plastic tubing attached to a plywood backboard (with base), two meter sticks as scales, and a No. 00 rubber stopper. Fill with colored water.

Open Manometer (glass), Cynmar Corp.

Boyle's Law, Charles' Law, and absolute zero temperature

Apparatus

- For Charles' Law: Thin high temperature flexible plastic tubing (e.g., Teflon®) about 1-2 feet long. Vinyl tubing, 3/8-inch o.d. (e.g., Tygon®) can be used for Boyle's Law demonstration.
- No. 00 rubber stopper for vinyl tubing and a suitable stopper or clamp for the Teflon tubing.
- Hot plate.
- Container of water large enough to contain the submerged coil of tubing.
- Thermometer with a range from 0°C to 100°C).
- Centimeter rule
- Black permanent marker pen, for use on any surface.

Charles' Law: $V_1 / T_1 = V_2 / T_2$

Coil the Teflon tube, this will have a certain volume of air trapped in the tube, which remains at a constant depth under the water. The container of water is heated on a hot-plate. Mark off the length in cm on this tubing starting from one end. Start with ice water (T_1). From the length of trapped air calculate the volume (V_1). Heat the water to near the boiling point of water (T_2) and again measure the length of trapped air and calculate the volume (V_2).

You can also estimate the value on the Celcius scale of absolute zero. Plot volume vs. temperature (in °C) and extrapolate to zero volume. Measure volume at room temperature, near freezing, and near boiling. A student's science fair project ended up using a small-diameter glass tube since she found that a plastic tube changed length with temperature.

Boyle's Law: $P_1 V_1 = P_2 V_2$

Apparatus: 3/8" ID vinyl plastic tubing, No. 00 rubber stopper, felt-tip permanent marker, and a container of water.

Partially immerse the tubing in the water. Plug the top of the tubing with the rubber stopper. Mark the water level on the tubing. Raise the tubing out of the water and notice that volume of the air increases. If you remove the stopper, air rushes in (pressure increases back to atmospheric as water level decreases).

If a pressure gauge is connected to the tubing, Gay-Lussac's Law ($P_1 / T_1 = P_2 / T_2$) can be demonstrated by creatively combining this experiment with the Charles's Law demonstration.

Demonstration of air pressure at Magdeburg, Germany 1657. Probably first demonstrated in 1648 by Otto von Guericke.

Iconismus XII (from von Guericke's book of 1672): Attempt to tear the evacuated copper hemispheres apart by applying weights. [Courtesy of the "Otto von Guericke" University, Magdeburg, Germany.]