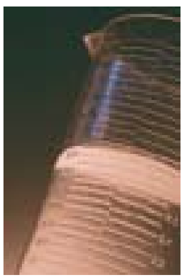
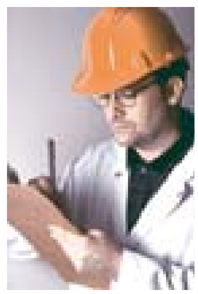
Exploring Thermal Properties Measurement of Natural & Engineered Materials

HEAT PULSE 2006





www.thermal.decagon.com

KD2 Pro Transforms Theory into Solid, Real-world Technology for Measuring Thermal Conductivity in Liquids

USING THE KD2 TO MEASURE THERMAL CONDUCTIVITY OF FLUIDS

For more technical information about using the KD2 to measure the thermal conductivity of liquids, visit www.decagon.com/appnotes/KD2_fluids.pdf

Other literature about measuring thermal conductivity with the KD2 is available at Decagon's website, www.thermal.decagon.com

FRIENDS OF KD2

ABB High Voltage Cable
Campbell Soup
FDA
Ford Motor Company
Frito Lay
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Kraft Foods
MIT
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Sandia National Labs
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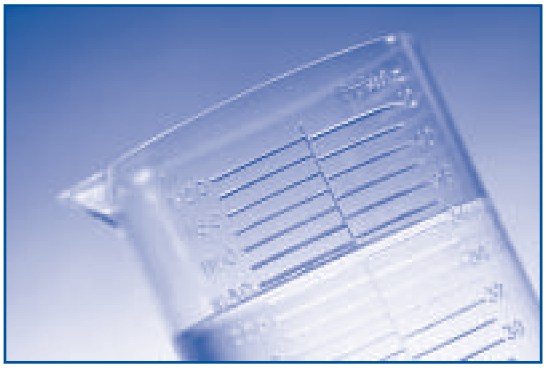
For more friends of KD2, please visit www.thermal.decagon.com/friends.htm

It's a tiny little thing, especially when compared to the large bench-top instruments most researchers use to measure thermal conductivity. And, at a fraction of the price, it's hard not to wonder whether this pocket-sized instrument can really do what it says it can do—measure thermal conductivity in less than two minutes using just one needlelike sensor.



▲ The KD2 Pro requires only a small sample size to make measurements.

Student Plants the Seed

Dr. Gaylon Campbell had his doubts when he first heard the method proposed back in the 1970's. His lab was doing lots of thermal properties research, and this method seemed flawed. "A student came over from Ag Engineering. He wanted to put a heater and a temperature sensor inside a probe and measure thermal conductivity that way. He had run across the method in some old literature. The idea had been around, but from my experience with other methods, I told him, 'There's no way you can get thermal conductivity out of that without knowing the other thermal properties of the soil.' I couldn't see how you could use a transient method without involving heat storage."

Insight from a Computer Model

Using computer models he was running for other research, Dr. Campbell set out to show the student why the method wouldn't work and discovered an interesting quirk. "Because the probe is inserted in the sample, the heat flow is limited so much by the material that's right around the [heat] source that the heat storage value drops out of the equation and you're left with the heat transfer values."

Complex Problem Made Simple

Decagon's KD2 Pro series evolved from early sensors built to take advantage of this discovery. The sensor itself looks like a hypodermic needle. The needle contains a heater and a temperature sensor. The sensor is connected to a controller which sends a heat pulse—just a few tenths of a degree C—to the sample and then monitors the result. It doesn't sound too complicated, but the devil is in the details. "It's a simple looking thing," says Dr. Campbell, "But it involves the deepest and most complicated math that

> They say 'This saves me so much time and energy, I can't believe we were using this other stuff before.'

I'm capable of doing." Luckily for the rest of us, all we have to do is push the button.

Multipurpose Instrument Excels with Liquids

The KD2 Pro is capable of measuring a wide variety of things—styrofoam, soil, insulation, food, organic materials, carpet fiber—but it has one of its most interesting applications in liquids.

Monitoring Drilling Fluid Life-span

One of these liquids is actually called mud. It's the high-tech substance used to flush the borehole when oil wells are drilled. As oil wells are drilled deeper,

the borehole must be drilled through more difficult geological architecture. Complex formulations of drilling fluid make this possible—balancing the pressure of the oil or gas, stabilizing the walls of the borehole, removing the rock cuttings without clogging the drilling system, and, critically, cooling the drill bit and cutting surface as the hole is drilled. Drilling fluid is pumped through the system, cleaned, and recirculated, but as you would expect from a component with so many functions, the fluid has a limited life-span. Researchers are using the KD2 Pro to monitor this life-span, measuring fluid breakdown as a reduction in thermal conductivity.

Thermal Conductivity Measurement Revolution

Other researchers are using the KD2 Pro for a wide variety of tasks—everything from designing pasteurization equipment for minimizing off-flavors and colors in syrups and sauces, to engineering car engines, to transferring heat more effectively. It's used to measure the thermal conductivity of oil, toothpaste, shampoo, and chocolate sauce. And it's so simple, and so inexpensive, that most researchers experience it as a revolution.

What's the Catch?

How can it be so much less expensive than the other available instruments? It seems a little too good to be true. Does it possibly have some serious limitations? "Well," admits Bryan Wacker, head of Decagon's Research Instruments division, "you can't stick a needle into a rock." Because the KD2 Pro probe must be inserted into the sample, certain samples can't be read at all. And other samples are subject to "contact resistance errors," meaning that what the probe can't adequately touch and heat, it can't

▲ KD2 Pro provides you with portable thermal resistivity measurements for the field and lab.

■ KD2 Pro's smaller needles result in less material disturbance during measurement.

Continued on page 5 ▶

Decagon to Measure Thermal Properties of Martian Soil

DECAGON CONTINUES to develop an instrument with a suite of sensors that will fly to Mars in 2007 on NASA's Phoenix Scout Lander. This sensor, called the Thermal and Electrical Conductivity Probe (TECP), will combine into one package a variety of measurements that Decagon's sensors measure here on Earth.

▲ The new KD2 Pro incorporates design innovations from the Mars Thermal and Electrical Conductivity Probe.

Measuring Four Properties of Martian Soil

In addition to measuring electrical and atmospheric properties, the TECP will measure four thermal properties of the Martian regolith (soil): temperature, thermal conductivity, thermal diffusivity, and volumetric heat capacity. Mars researchers use these measurements to develop Global Climate Models (GCM's) for Mars. GCM's enable researchers to understand Martian weather patterns, how heat penetrates the Martian surface, and how water is transported through the Martian atmosphere. This circulation of water vapor is of keen interest to the Mars research community.

Accurate *in situ* Measurement

Sensors on previous Mars orbiters have measured regolith thermal properties from space using remote sensing techniques. However, remote sensing of regolith thermal properties is not as accurate as *in situ* measuring from the Martian surface. TECP's *in situ* measurements will provide increased accuracy to augment and improve the entire library of satellite-based measurements.

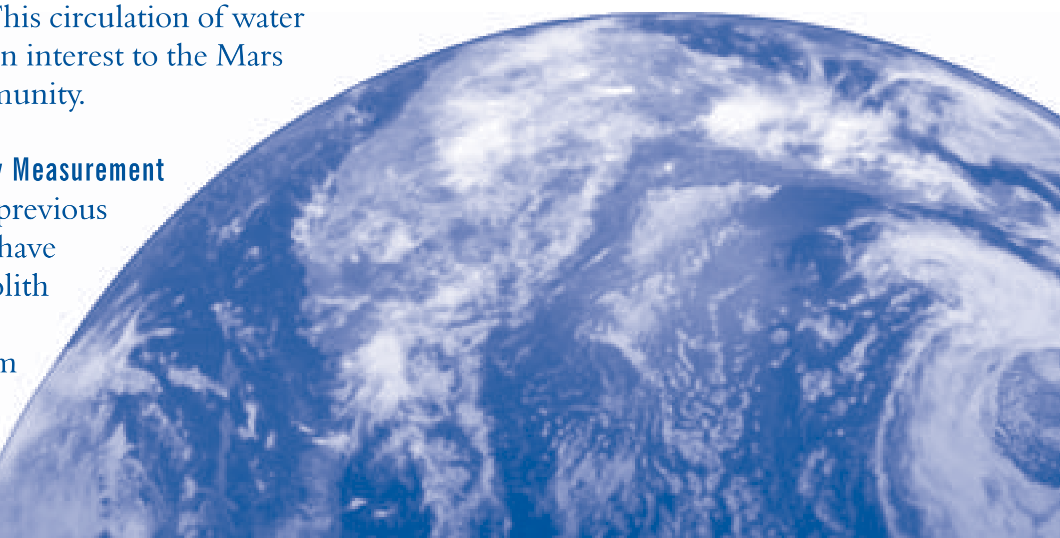
Probing Floor and Walls of Martian Trench

The TECP consists of four metal needles mounted into a plastic and aluminum housing, which will attach to the Phoenix's robotic arm. The robotic arm has an articulated scoop that will excavate a trench in the Martian surface, allowing the instrument to probe the floor and walls of the trench.

Scientific Integrity

Nearly all of the engineering on the TECP has been completed and tested to rigorous NASA standards. Because it is impossible to elucidate anomalous data once the sensor has been sent into space, understanding how the sensor behaves under various conditions is imperative to taking accurate measurements once on Mars. To this end, Decagon continues to test and calibrate the instrument functions to ensure the scientific integrity of returned data. ■

▼ Understanding Mars helps us understand our home planet. Earth is formed predominantly of water. Understanding thermal conductivity helps unlock Earth's and Mars' natural mysteries.



DECAGON'S MARS TIMELINE

DECEMBER 2002
Jet Propulsion Laboratory (JPL) scientists see Decagon's KD2 thermal properties meter and ECH_2O water content probes at American Geophysical Union meetings in San Francisco.

MARCH–AUGUST 2003
JPL persuades Decagon to engineer a probe for the 2007 Phoenix Scout mission to Mars.

JANUARY 2004
Contract signed for Decagon to make prototype Thermal and Electrical Conductivity Probe (TECP).

MAY 2004
Decagon completes prototype.

OCTOBER 2004
Engineering models delivered for testing. Engineering models share form, fit, and function with the planned flight models.

OCTOBER 2005
All parts for flight units delivered to JPL.

APRIL 2006
Flight units finished; calibration begins.

MAY 2006
Flight TECPs delivered.

AUGUST 2007
Phoenix Launch (Kennedy Space Center).

MAY 2008
Phoenix lands on Mars.

~AUGUST 2008
Phoenix mission complete.

KD2 Pro Measures Thermal Conductivity in Liquids

▶ Continued from page 3

measure. These errors can be reduced or even eliminated by using thermal grease on the probe *(see the application note available online at www.decagon.com/appnotes/contactresistance.pdf).*

Conduction vs. Convection

In liquids, the KD2 Pro may have some limitations, too. Measuring thermal conductivity in liquids can be tricky, because they're … well … fluid. Conduction—the transfer of heat by *molecular* agitation—must be distinguished from convection—the transfer of heat by mass motion of the fluid itself—in order to get an accurate reading. Convective heat transfer can come from something as inadvertent as jiggling the sample. It can be the result of any shaking or mixing of the liquid, and because heat transfer by convection can be significantly higher than heat transfer by conduction, its effects can cause significant inaccuracies. Convection can also result from something hotter or cooler being stuck into the object—something like the sensor itself.

Reducing Convection Errors

"Fortunately, the KD2 Pro heats the sensor just a few tenths of a degree," says Decagon Research Scientist Doug Cobos. "That's much less than the heating normally associated with the single-needle heat pulse technique, and that really minimizes error from free convection." Errors from free convection can also come from the viscosity of the sample and the orientation of the probe during measurement.

How Does Fluid Viscosity Affect Measurements?

Measurements on more viscous samples, such as castor oil, are not affected by free convection. Less viscous fluids, like water, can be significantly affected. Low viscosity fluids may be stabilized to give better readings—in fact, thermal properties probes are commonly calibrated in water, but only after the water has been stabilized with a thickener. And for anything less viscous than water? "Throw it out the window," advises Dr. Cobos.

Proper Orientation May Improve Accuracy

Additionally, the way you put the sensor in the fluid matters. That's because of the way the heat pulse from the probe creates free convection. If the probe is oriented horizontally, the heated molecules tend to move upward away from the probe and through the sample in a nonuniform direction. If the probe is oriented vertically, fluid molecules tend to stay close to the probe, and the heat is transferred uniformly on all sides of the probe. So, orienting the probe vertically may mean more accurate measurements.

Optimum Measurement Range Includes Most Samples of Interest

The KD2 Pro has a limited range—0.02 to 2 watts per meter °C. "You won't be measuring the thermal conductivity of molten metal with this instrument," observes Bryan Wacker. But for most samples of interest to researchers—soils, foods, fluid formulations—the KD2 Pro is a perfect blend of speed, accuracy, and portability.

Solid Proven Technology

"I actually like to take the KD2 Pro [customer support] calls," admits Dr. Cobos, "because users like this instrument so much. They say 'This saves me so much time and energy, I can't believe we were using this other stuff before.' It's small, it's simple, it's inexpensive—it's such a solid instrument." ■

DECAGON DEVICES

▲ The KD2 Pro is ideal for measuring thermal properties of viscous liquids.

TR-1 (10 cm sensor)
The TR-1 measures thermal conductivity and thermal resistivity and conforms to IEEE Standard 442-1981 and ASTM Standard D 5334-00

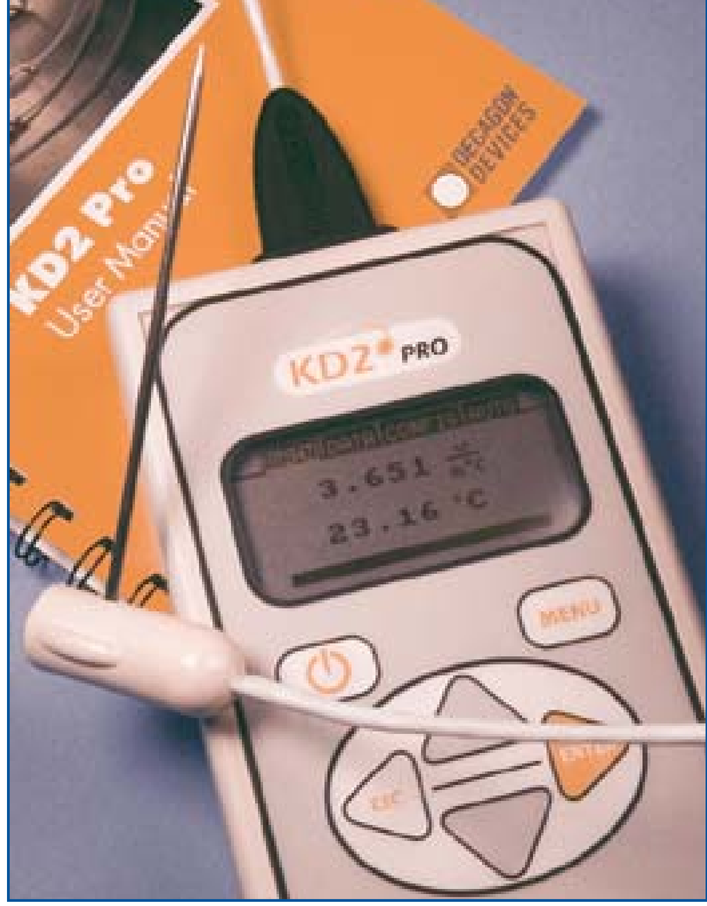
KS-1 (6 cm sensor)
The KS-1 is ideal for measuring thermal conductivity and thermal resistivity. Conforms to ASTM Standard D 5334-00.

SH-1 (30 mm dual needle sensor)
The SH-1 is the only sensor that measures thermal diffusivity and specific heat.

Rammed Earth Houses

Rammed earth houses have been built for centuries, although if you haven't heard of them, you're not the first one. The method is old and attractive because the materials are so readily available (they came with the lot you just bought for your new house). Rammed earth is an earth/cement mixture (about 8% water and 3% cement) that is compacted in a forming system. When the forms are removed after the rammed earth is dry, they reveal the new wall.

The really attractive part of rammed earth is how cool the interior of the house feels on a hot summer day. The thick rammed earth (or adobe) walls absorb heat energy and gradually transfer it to the interior of the home—which stabilizes the interior temperature. This phenomenon of slow heat transfer is known as thermal mass, and it can enhance your building's R-value. The use of thermal mass is especially effective in climates where there are extreme temperature shifts between night and day. The stable interior temperature requires fewer heating and cooling cycles by the building's HVAC system and saves wear and tear on equipment.



▲ In addition to thermal conductivity and thermal resistivity, the new KD2 Pro measures thermal diffusivity and specific heat (heat capacity).

Your local building inspector will want to know the R-value of your earth walls. R-value is an indication of a material's resistance to heat flow—the higher the R-value, the better the insulating properties. The KD2 and KD2 Pro are ideal for measuring thermal properties of materials. When Bob from Ephrata, Washington was building his rammed earth house, he contacted Decagon to help him determine its R-value. Since we are close by, he brought in a section

www.thermal.decagon.com

Care must be taken in selecting soil types for the building of earth structures. An approach that performs well in the Middle East, for example, may not be suitable for Africa.

Earth building is in resurgence, but modern applications demand higher standards and greater care in construction. Decagon's KD2 helps builders comply with these standards.

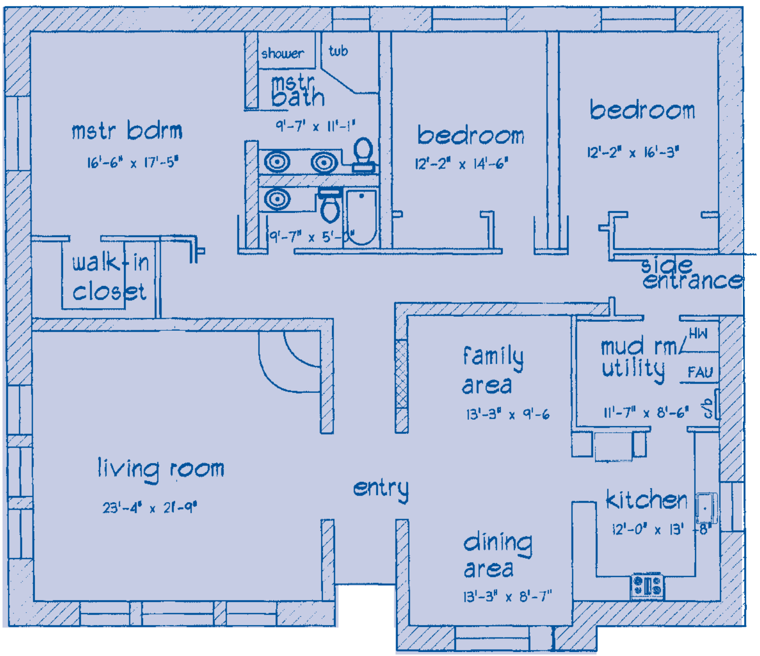
A material's R-value is the measure of its resistance to heat flow. It is important to know the R-value because many states or regions require a roof system have a minimum thermal resistance on commercial, industrial, and/or institutional buildings. The higher the R-value, the more the material insulates.

of wall for us to test. We used a KD2 to make the measurement and then used the application note in the Decagon library to calculate the R-value. This satisfied the local code requirements and made his building inspector happy.

This all sounds nearly perfect. Before you go build your own adobe dream house there is a caveat—although made of dirt, they are not dirt cheap. On average, rammed earth homes are significantly more expensive than a standard home. Of course, the energy efficiency may make up for that additional cost. ■

If you would like to learn more about adobe houses and R-value calculations, please visit the following links:

www.thermal.decagon.com/applications.htm
www.earthbuilder.com
www.rammedearthworks.com
www.adobe-home.com
www.rammedearth.com
www.roofhelp.com/rvalue.htm



◄ Raw earth is the world's most widely used building material. Throughout recorded history artisans and village builders have used it to create durable housing.

THERMAL UNITS CONVERSION CHART

To convert column 1 into column 2, multiply by:	Column 1	Column 2	To convert column 2 into column 1, multiply by:
heat			
0.000952	Joule	Btu	1054
heat			
0.239	Joule	Cal	4.186
heat flux density			
0.00 143	W/m^2	cal cm^{-2} min^{-1}	698
diffusivity			
10.76	m^2/s	ft^2/s	0.0929
diffusivity			
3.88×10^4	m^2/s	ft^2/hr	2.58×10^{-5}
thermal conductivity			
0.578	W $m^{-1}C^{-1}$	Btu $hr^{-1}ft^{-1}F^{-1}$	1.73
thermal conductivity			
6.93	W $m^{-1}C^{-1}$	Btu in $hr^{-1}ft^{-2}F^{-1}$	0.144
thermal resistivity			
1.73	C m/W	ft hr F Btu^{-1}	0.578
thermal resistivity			
0.144	C m/W	ft^2 hr F Btu^{-1} in^{-1}	6.93
specific heat			
2.39×10^{-4}	J $kg^{-1}C^{-1}$	Btu lb^{-1} F^{-1}	4179

DEFINITIONS

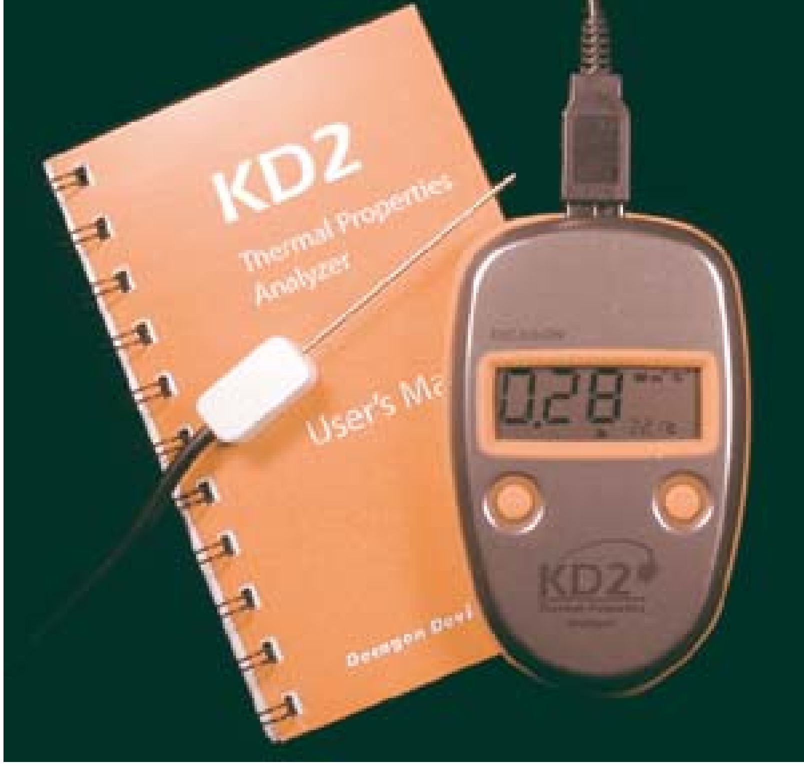
THERMAL CONDUCTIVITY The amount of heat conducted across unit area when unit temperature gradient is applied.

SPECIFIC HEAT The amount of heat stored per unit mass or volume for a unit temperature change.

THERMAL DIFFUSIVITY The ratio of thermal conductivity to volumetric specific heat. A measure of the speed with which a thermal disturbance is propagated in a medium.

▲ This thermal units conversion chart helps compare thermal units across disciplines.

► The original KD2 fits in the palm of your hand and measures thermal conductivity and resistivity.



Decagon builds thermal research instrumentation.

For the past 23 years, Decagon has manufactured quality scientific instrumentation that measures thermal properties and moisture in food, soils, and other porous materials. Our instruments are in use throughout the world in organizations of all sizes, including universities, research and testing laboratories, state and government agencies, wineries, and industrial testing facilities. Recognized as a world leader in the markets we serve, Decagon was selected to design an instrument that will fly to Mars on the 2007 Phoenix Scout Lander and test thermal properties of Martian soil.

▼ Durable protective cases included with the purchase of a KD2 or KD2 Pro.

Scientists at Decagon first measured thermal conductivity in the late 1970's. This was done by putting a temperature sensor in a soil sample and suspending it in a constant temperature bath. This initial work was done for modeling heat and water transfer through soil. In 1985, Decagon manufactured its first thermal conductivity instrument, the PC-1. Today, Decagon features the handheld KD2 for measuring thermal conductivity and thermal resistivity, and the KD2 Pro for measuring thermal conductivity, thermal resistivity, thermal diffusivity, and specific heat (heat capacity). ■

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