KD2 Thermal Properties Analyzer

User's Manual

version 1.0

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Contents

1. Introduction 1
About the KD2 1
KD2 Specifications 2
Contact Information 2
Warranty Information 3
Seller's Liability 3

2. Operation 5
Turning it on 5
Taking Measurements 6
How the KD2 takes measurements 11

3. Care and Maintenance 13
Cleaning 13
Battery Replacement 13
Caring for the Probe 15

4. Theory 16

Declaration of Conformity 22

1. Introduction

Welcome to your new KD2 Thermal Properties Analyzer. This guide is designed to help you understand and use your instrument to the best of its capability.

About the KD2

The KD2 is a compact, portable meter used to measure thermal properties. It consists of a hand-held readout and a single-needle sensor that can be inserted into the medium you wish to measure. A reading is initiated by pressing the left button on the readout. The controller waits for 90 seconds to ensure temperature stability, then heats the probe for 30 seconds. At the end of the reading, the controller computes the thermal properties based on the measurements made during the heating period of the probe. This data is used to calculate thermal conductivity, thermal resistivity, and thermal diffusivity. Further details about the measurements and how they're made are given in chapters 2 and 3 of this guide.

KD2 Specifications

Measurement Speed: 2 minutes
Accuracy:

- 5% Thermal Conductivity/Resistivity
- 10% Thermal Diffusivity

Power: 3.0V CR2-type lithium-ion battery
Weight: 148g (5 oz.)
Operating Environment: 5 to 40°C
Range of Measurement:

- K (thermal conductivity): 0.1—2 $Wm^{-1}C^{-1}$
- D (thermal diffusivity): 0.1—1.0 mm^2s^{-1}
- R (thermal resistivity): 0.5—10mC W^{-1}

Sensor:

- Needle length: 60mm
- Needle diameter: 0.9mm
- Cable length: 72cm

Contact Information

If you need to contact Decagon for customer support or any other questions, you can reach us by any of the following:

- **Email** us at **kd2@decagon.com**

- Send us a **fax** at: **(509) 332-5158**
- **Call** us at: **1-800-755-2751** (US and Canada only) or **509-332-2756**.

Warranty Information

The KD2 has a 30-day satisfaction guarantee and a one-year warranty.

Seller's Liability

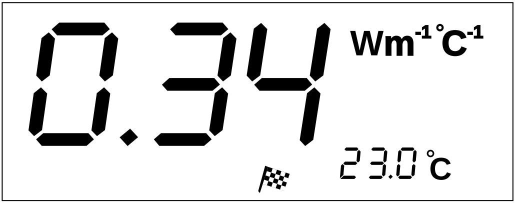
Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not to be considered a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts F.O.B. the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things of whatsoever kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, nonuse, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitutes Buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

2. Operation

The KD2 is designed to be a simple, easy to use instrument that will allow you to make quick and accurate thermal properties measurements. Following are some instructions on how the instrument functions.

Turning it on

To turn on the KD2, press the left button (**I**) once. The LCD display will appear, showing the previous measurement taken.



Taking Measurements

The KD2 measures thermal conductivity, resistivity, and diffusivity at the same time from one measurement, but can only display one reading at a time after the measurement is made. The right (**II**) button is used to toggle through the calculated readings after the measurement has been made. To begin a measurement, press the left (**I**) button to turn on the instrument. The instrument will be in the same measurement mode as it was when it was last used (thermal conductivity, thermal diffusivity, or thermal resistivity mode) and will display the last reading taken.

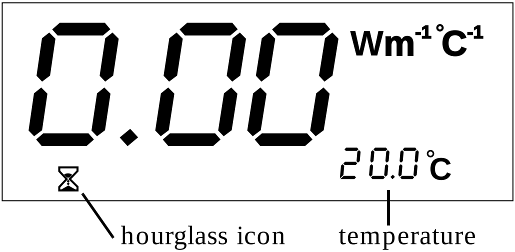
NOTE!: It is important to wait for about 5 minutes between readings if the probe is left in the same location! If multiple measurements of a sample are made too rapidly in succession, the sample's temperature will not have had enough time to equilibrate from the previous reading, and the resulting measurement will be inaccurate. For best results, the sample should be as close to equilibrium as possible. An ideal environment for equilibration can be accomplished by placing the

KD2 probe and sample in an isothermal chamber or styrofoam box.

How to Start the Measurement

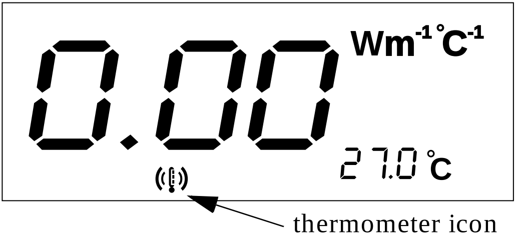
Once the instrument is on, do the following:

1. Carefully insert the probe into your medium.
2. Press the left button to begin the measurement process. The instrument will first equilibrate for 90 seconds. During this time you will be able to see that it is equilibrating by the blinking "hourglass" icon below the value. The temperature measured by the probe will be displayed in the lower right corner of the screen:



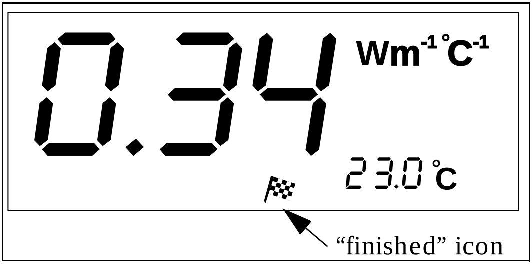
***Note!:** Make sure to watch the temperature during the equilibration stage to make sure it doesn’t drastically fluctuate or rapidly change. If the temperature is still rapidly changing, pull the probe out of the sample and wait until the sample temperature is stable before measuring again.*

3. After equilibrating, it begins its 30-second heating and measurement cycle. During this stage of measurement you will see a blinking thermometer icon appear, and the temperature reading will increase:



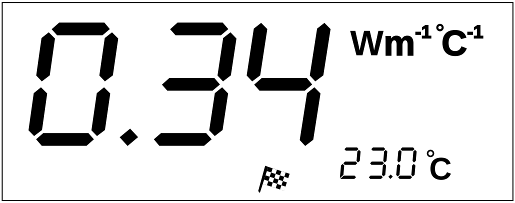
4. When the reading is finished, the checkered “finish line” flag will blink on the screen, and a final reading will be dis-

played along with the sample temperature:



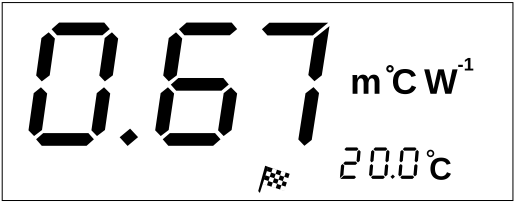
Thermal Conductivity

To display the measurement in terms of thermal conductivity, press the right (**II**) button until the thermal conductivity is displayed in $Wm^{-1}C^{-1}$ (watts per meter-degree Celsius):



Thermal Resistivity

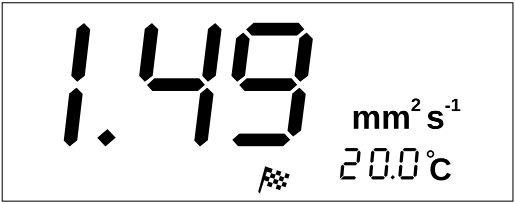
To display the measurement in terms of thermal resistivity, press the right (**II**) button until the thermal resistivity is displayed in mC W^{-1} (meter-degrees C per watt):



If the value shown for thermal resistivity is 9.99, this indicates that your sample is out of range for the KD2 to measure.

Thermal Diffusivity

To display the measurement in terms of thermal diffusivity, press the right (**II**) button until the thermal diffusivity is displayed in $mm^2\ s^{-1}$ (square millimeters per second):



Turning it off

The KD2 will shut off automatically after 5 minutes of inactivity. To turn it back on, press the left (**I**) button once.

How the KD2 takes measurements

The KD2's sensor needle contains both a heating element and a thermistor. The controller module contains a battery, a 16-bit microcontroller/AD converter, and power control circuitry.

When you begin a measurement, the microcontroller waits for 90 seconds for temperature stability, then applies a known amount of current for 30 seconds to a heater in the probe that has an accurately known resistance. The microprocessor calculates the amount of power supplied to the heater. The probe's thermistor measures the changing temperature for 30 seconds while the microprocessor stores the data. At the end of the reading, the controller computes the thermal conductivity and diffusivity using the change in temperature (ΔT) vs. time data. Thermal resistivity is computed as the reciprocal of thermal conductivity.

3. Care and Maintenance

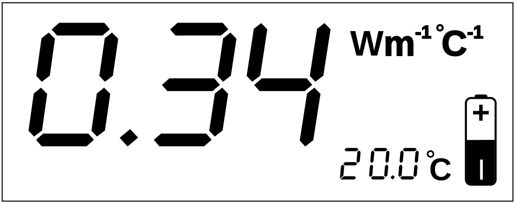
Your KD2 should require a minimum amount of maintenance. Following are instructions for cleaning and battery replacement, as well as considerations for the KD2 probe.

Cleaning

The KD2's controller is stainless steel. If it needs cleaning, do so with a damp cloth. ***Do not immerse it in water.*** Clean the LCD readout with a soft, damp cloth moistened with water or a glass cleanser. Do not use tissue or other wood-based fibers, as they can scratch the plastic LCD screen.

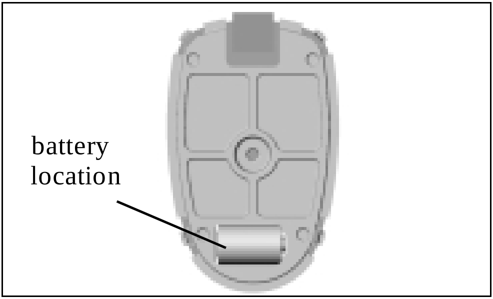
Battery Replacement

The KD2 uses a 3.0V CR-2 type Lithium-ion battery. It typically should last for about 1000 measurements. If the battery charge is getting low, a low-battery indicator icon will appear in the lower right corner of the LCD screen when the heater comes on (an occasional low battery indication does not necessarily mean the battery needs replacing):



If this screen appears continually, do the following to replace the battery:

1. Unscrew the small screw on the back of the KD2 case.
2. Lift the back shell off to reveal the battery:



3. Remove the battery and replace it with the new one, making sure to orient the battery the same way you removed it.

Caring for the Probe

The KD2 sensor contains a heater and thermistor that are essential for the function of the instrument. Care should be taken to prevent bending the probe. The probe itself is stainless steel, so it may be cleaned with a wet cloth or sponge if it becomes dirty.

4. Theory

KD2 calculates its values for thermal conductivity (K), resistivity (R), and diffusivity (D) by monitoring the dissipation of heat from a line heat source given a known voltage.

The equation for radial heat conduction in a homogeneous, isotropic medium is given by

$$\frac{\partial T}{\partial t} = \kappa\left(\frac{\partial^2 T}{\partial r^2} + r^{-1}\frac{\partial T}{\partial r}\right) \tag{1}$$

where T is temperature (°C), t is time (s), κ is thermal diffusivity ($m^2\ s^{-1}$), and r is radial distance (m). When a long, electrically heated probe is introduced into a medium, the rise in temperature from an initial temperature, T_0, at some distance, r, from the probe is

$$T - T_0 = \left(\frac{q}{4\pi\lambda_h} \right) Ei \left(\frac{-r^2}{4\kappa t} \right)$$

(2)

where q is the heat produced per unit length per unit time (W m^{-1}), λ_h is the thermal conductivity of the medium (W $m^{-1}c^{-1}$), and *Ei* is the exponential integral function

$$-Ei(-a) = \int_a^{\infty} \left(\frac{1}{u} \right) \exp(-u) du = -\gamma - \ln\left(\frac{r^2}{4\kappa t} \right) + \frac{r^2}{4\kappa t} - \left(\frac{r^2}{8\kappa t} \right)^2 + \ldots$$

(3)

with $a = r^2/4\kappa t$ and γ is Euler's constant (0.5772…). When t is large, the higher order terms can be ignored, so combining Eqs. (2) and (3) yields

$$T - T_0 \cong \frac{q}{4\pi\lambda_h} \left(\ln(t) - \gamma - \ln\left(\frac{r^2}{4\kappa} \right) \right)$$

(4)

It is apparent from the relationship between thermal conductivity and $\Delta T = T - T_0$, shown in

Eq. (4), that ΔT and $ln(t)$ are linearly related with a slope $m = (q/4\pi\lambda_h)$. Linearly regressing ΔT on $ln(t)$ yields a slope that, after rearranging, gives the thermal conductivity as

$$\lambda_h \cong \frac{q}{4\pi m} \tag{5}$$

where q is known from the power supplied to the heater. The diffusivity can also be obtained from Eq. (4). The intersection of the regression line with the t axis ($\Delta T = 0$) gives

$$\ln(t_0) = \left(\gamma + \ln\left(\frac{r^2}{4\kappa}\right)\right) \tag{6}$$

From the calculated t_0 (from the intercept of ΔT vs. $ln(t)$) and finite r, Eq. (6) gives the diffusivity.

Because the higher order terms of Eq. (3) have been neglected, Eq. (4) is not exact. However, if the slope and intercept are computed only for ΔT and $ln(t)$ values, where t is large enough to ignore the higher order terms, Eq. (5) and (6) give correct values for λ_h and κ. To verify these relationships, realistic values of λ_h and κ were supplied to Eq. (2), varying both λ_h and volumetric heat capacity (ρc_p), and the resulting slope and intercept tabulated for *t* ranging from 1 to 30 s. Plots of slope vs. theoretical λ_h and *ln*(intercept) vs. *ln*(theoretical κ) show an exact linear relationship (Fig. 1 and 2, respectively) with low cross-covariance.

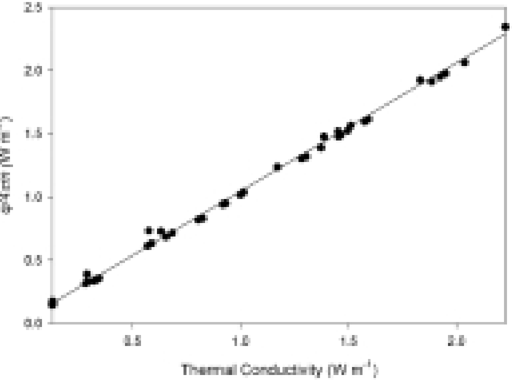


Figure 1: calculated λ_h vs. theoretical λ_h

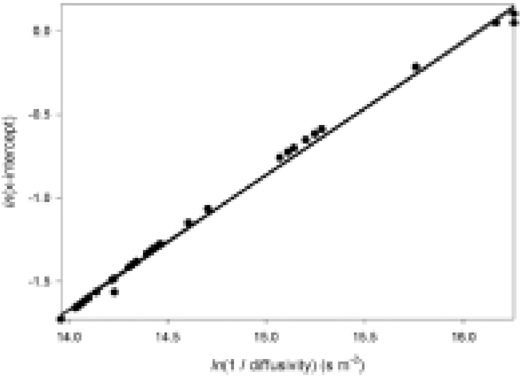


Figure 2: calculated κ vs. theoretical κ

The experimental analysis differs from the theoretical shown in Eq. (2) in that the heater and sensor have their own conductivity and diffusivity, which, in general, differ from those of the medium being measured. We have shown experimentally that the relationships in Eq. (5) and (6) still allow calculations of λ_h and κ, but empirical factors must be introduced to correct for heater thermal properties.

Assumptions: The thermal conductivity measurement assumes several things: the long heat source can be treated as a infinitely long heat source, the medium is both homogeneous and isotropic, and a uniform initial temperature, T_0. Although these assumptions are not true in the strict sense, they are adequate for accurate thermal properties measurements.

Declaration of Conformity

Application of Council Directive:	89/336/EEC
Standards to which conformity is declared:	EN55022:1987 EN500082-1:1992
Manufacturer's Name:	Decagon Devices, Inc. 950 NE Nelson Court Pullman WA 99163 USA
Type of Equipment:	Thermal Properties Meter
Model Number:	KD2
Year of First Manufacture:	2001

This is to certify that the KD2 Thermal Properties Meter, manufactured by Decagon Devices, Inc., a corporation based in Pullman, WA, USA meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

Index

A

accuracy 2

B

battery

replacing 13

type 13

C

CE

compliance 22

cleaning 13

contact information 2

D

D (diffusivity) 16

E

email 2

F

fax number 2

K

K (thermal conductivity) 16
KD2
  overview 1
  specifications 2

L

low battery indicator 13

M

maintenance 13
measurement
  method 11
measurement range 2

O

off(turning off) 11
on(turning on) 5
operation

on 5

P

probe

maintenance 15

specifications 2

R

R (thermal resistivity) 16

range 2

S

seller's liability 3

specifications 2

T

telephone number 2

temperature equilibrium 6

theory 16

assumptions 21

thermal conductivity

calculation 18

thermal diffusivity
calculation 18
units 11
thermal resistivity
computed 12
units 10

U
units
thermal diffusivity 11
thermal resistivity 10

W
warranty 3