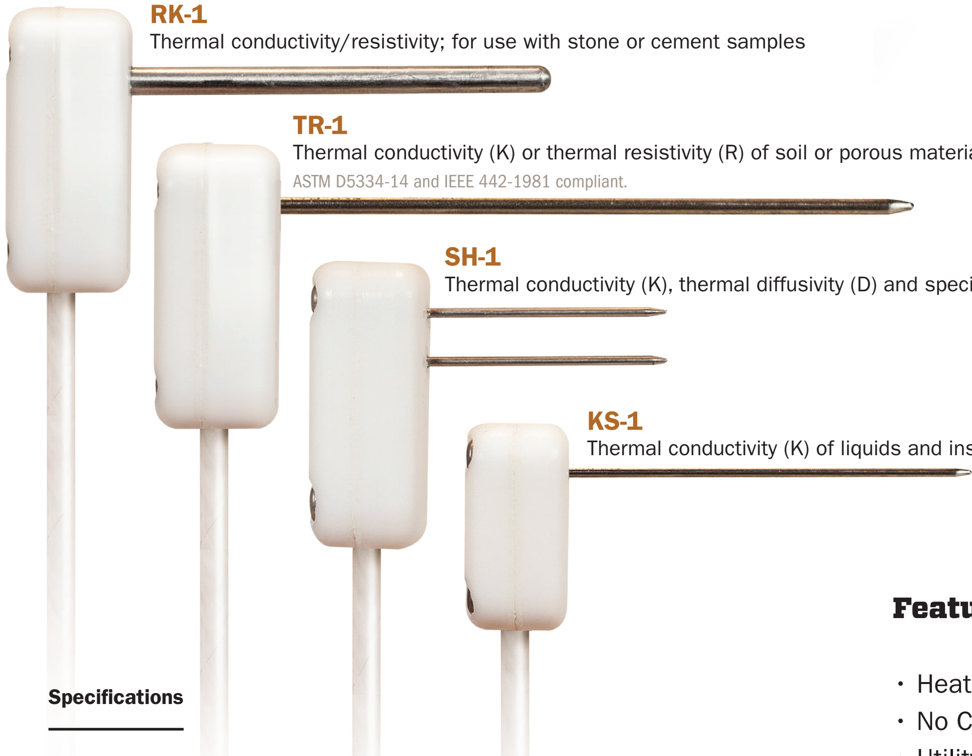
Model Heat Movement

Measure heat transfer in the soil-plant-atmosphere continuum with the KD2 Pro Thermal Properties Analyzer. The KD2 Pro has four interchangeable sensors which measure thermal conductivity, thermal diffusivity and specific heat (heat capacity) with onboard data storage and downloadable capabilities and an automatic data collection mode.

Each KD2 Pro comes factory calibrated and includes performance verification standards



RK-1
Thermal conductivity/resistivity; for use with stone or cement samples

TR-1
Thermal conductivity (K) or thermal resistivity (R) of soil or porous materials
ASTM D5334-14 and IEEE 442-1981 compliant.

SH-1
Thermal conductivity (K), thermal diffusivity (D) and specific heat (C)

KS-1
Thermal conductivity (K) of liquids and insulation

Features:

- Heated Needle Technology
- No Calibration Required
- Utility Software Allows for Data Downloads
- Small Needle Minimizes Material Disturbance

Specifications

Measurement Time: 90 seconds to 10 minutes. **Accuracy***: ±5 to ±10% Conductivity/Resistivity, ±10% Thermal Diffusivity, ±10% Specific Heat. **Ranges***: K: 0.02 to 6 Wm^{-1} C^{-1}, D: 0.1 to 1.0 mm^{2}s^{-1}, R: 0.25 to 50 mC W^{-1}, C: 0.5 to 4 MJ m^{-3} C^{-1}. **Data Storage:** 4095 readings. **Sensor Environment:** –50 to 150 °C. **Case Size:** 15.5 x 9.5 x 3.5 cm. **Power:** 4 AA Batteries **Cable:** 1 m.

*Accuracy and measurement range vary with sensor type.

Table 1. Thermal properties of soil materials (T is Celsius temperature) [modified from Campbell and Norman, 1998]

Material	Density (g cm^{-3})	Specific Heat (J g^{-1}K^{-1})	Thermal Cond. (W m^{-1}K^{-1})	Thermal Resistivity (m K W^{-1})
Soil Minerals	2.65	0.87	2.5	0.40
Granite	2.64	0.82	3.0	0.33
Quartz	2.66	0.80	8.8	0.11
Glass	2.71	0.84	1.0	1.00
Organic Matter	1.30	1.92	0.25	4.00
Water	1.00	4.18	0.56+0.0018T	1.65 at 25 °C
Ice	0.92	2.1+0.0073T	2.22-0.011T	0.45 at 0 °C
Air (101 kPa)	(1.29-0.0041T x 10^{-3})	1.01	0.024+0.00007T	38.8 at 25 °C

1. Campbell, G. S. and J. M. Norman. 1998. *An Introduction to Environmental Biophysics*, 2nd Ed. Springer Verlag, New York.
2. Campbell, G. S., J. D. Jungbauer, Jr., W. R. Bidlake and R. D. Hungerford. 1994. "Predicting the effect of temperature on soil thermal conductivity." *Soil Sci.* 158:307-313.
3. De Vries, D. A. 1963. "Thermal properties of soil." *Physics of Plant Environment.* W. R. van Wijk (ed.) North Holland Pub. Co. Amsterdam pp. 210-235.

Thermal Conductivity of Soils and other Porous Materials Changes Depending on Density, Water Content, Temperature and Composition.

Soils and other porous materials vary in density, water content, temperature and composition, which affects their thermal conductivity. Table 1 shows thermal properties of typical soil constituents. These constituents occur as mixtures in soils. The thermal conductivity of the mixture is quite difficult to compute, since it depends, not only on the thermal conductivities of the components, but also on their geometric arrangement. Methods for making this computation are given by deVries (1963) and Campbell and Norman (1998). These methods were used to compute the thermal conductivity of soils as they vary with water content, composition, density and temperature. The results of these computations are shown in Figures 1, 2 and 3.

In general, the thermal conductivity of a mixture is strongly influenced by the component with the lowest conductivity. Oven dry quartz sand and loam soil have about the same conductivity, even though the conductivity of the minerals differs by a factor of three (Figure 1 and Table 1). As the limiting conductivity gets higher, differences in the conductivities of the other components have a larger effect. For example, dry quartz and loam differ in conductivity by about 10%, while water saturated loam has about half the conductivity of saturated quartz sand (Figure 1).

As the water content of soil decreases, a threshold is reached where conductivity decreases rapidly with decreasing water content. This is evident in all three figures. This threshold is more closely related to the hydraulic properties than the thermal properties of the material. It is the water content at which liquid water can't flow across particle surfaces to re-evaporate and transport latent heat across pores in the medium.

In other words, the soil acts like a "heat pipe," an engineering device which makes use of latent heat transport for rapid and effective heat transfer. In a moist soil at room temperature 10 to 20% of the total heat transport is as latent heat through the pores. This portion of the heat transport is strongly temperature dependent, roughly doubling for each 10 °C temperature rise.

The effective thermal conductivity of moist, air-filled pores is about the same as the thermal conductivity of water at 60 °C, so, at this temperature, changing the water content of the material does not affect its conductivity. In Figure 3, the 65 °C curve shows almost no change in conductivity with increasing water content once the water content is high enough to sustain the liquid return flow within the pores.

www.decagon.com/kd2pro
Watch a three and a half minute video about measuring soil thermal conductivity with the KD2 Pro.

Figure 1. **Response of Solids**
Soil Thermal Conductivity

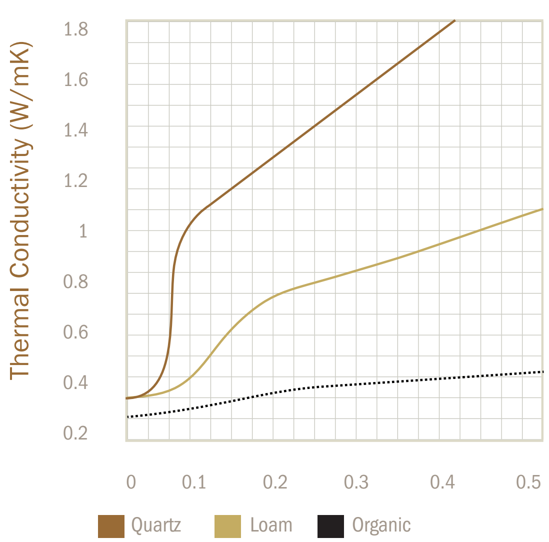


Figure 2. **Temperature Dependence**
Soil Thermal Conductivity

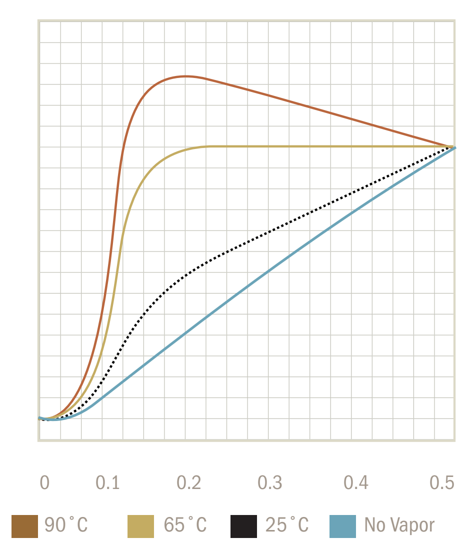
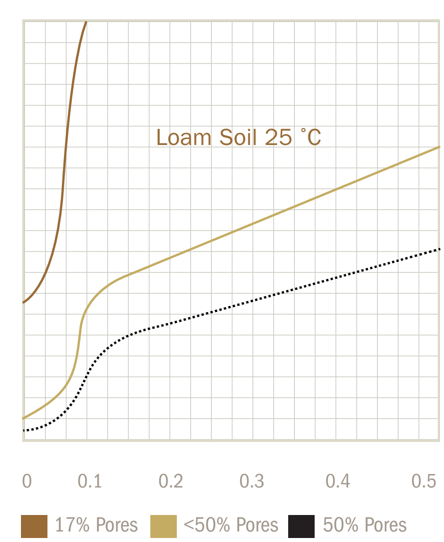


Figure 3. **Response to Compaction**
Soil Thermal Conductivity



Water Content (m^3/m^3)