High-temperature thermal conductivity measurements of macro-porous graphite

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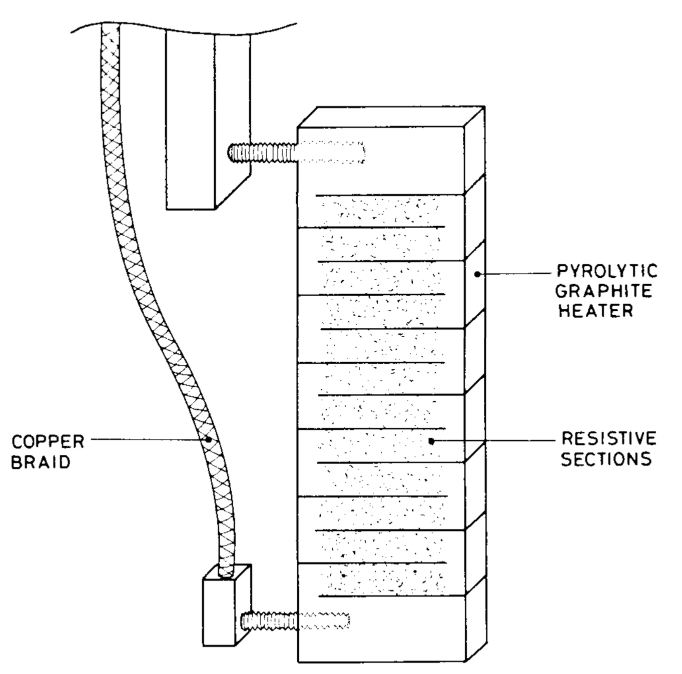
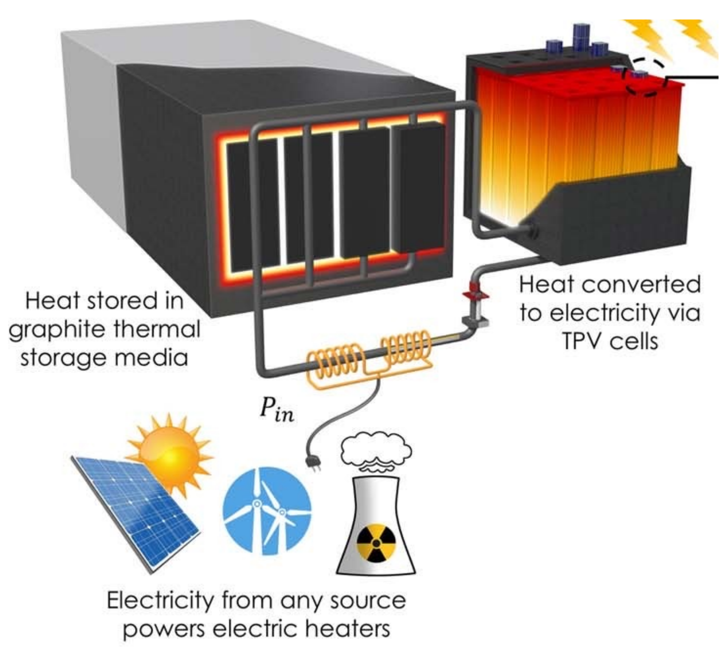
Graphite is used in many high-temperature industrial applications

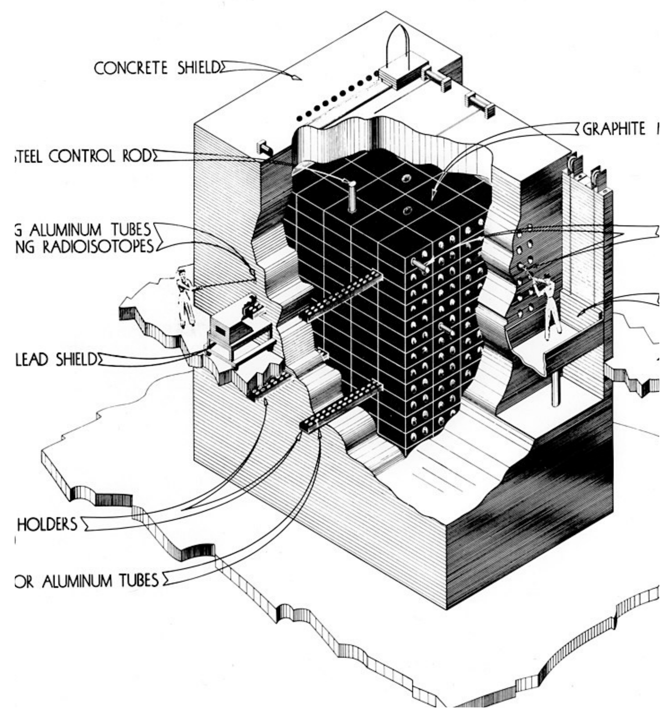
Resistive heating elements



Thermal energy storage

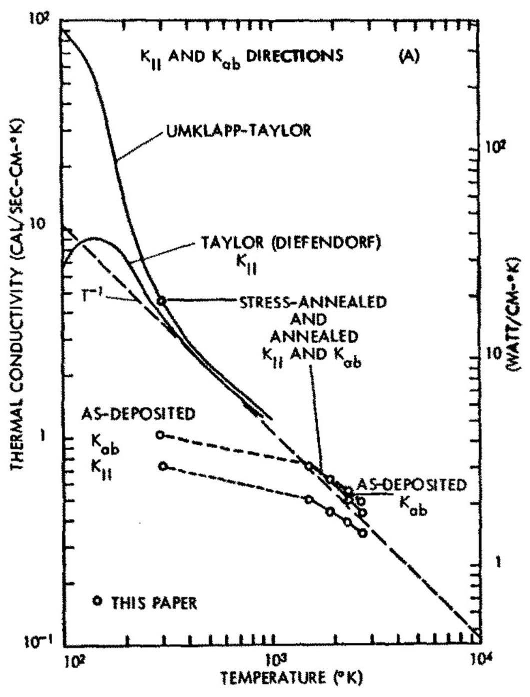


Nuclear reactors

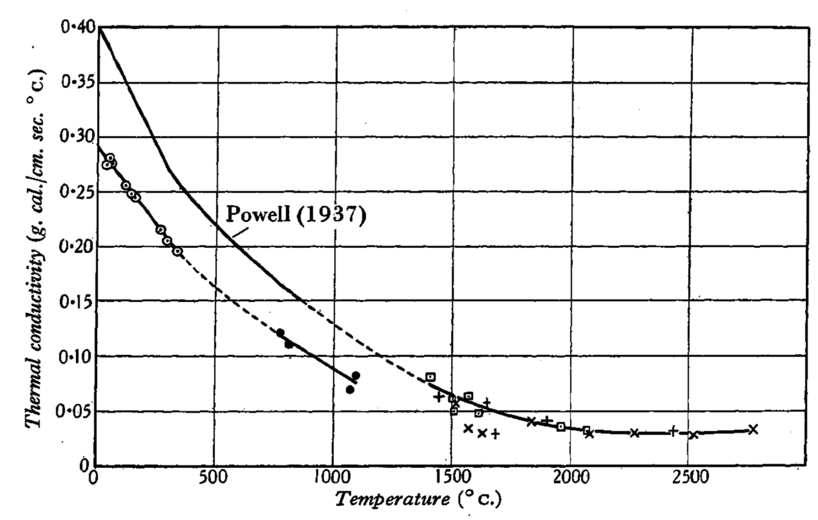


Low-quality (cheaper) graphite will become important as we attempt to decarbonize industry cost-efficiently

We need to measure thermal properties of low-quality graphite



Pyrolytic graphite



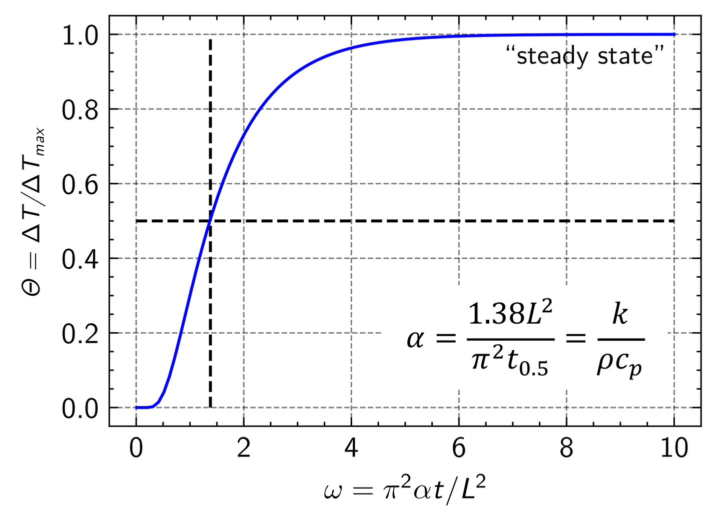
Acheson graphite

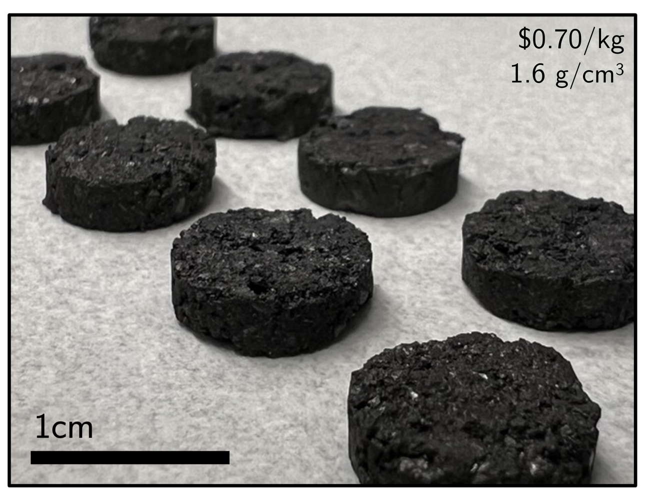
Literature gap: low-quality graphite

Measurements up to 1200°C with putty coating

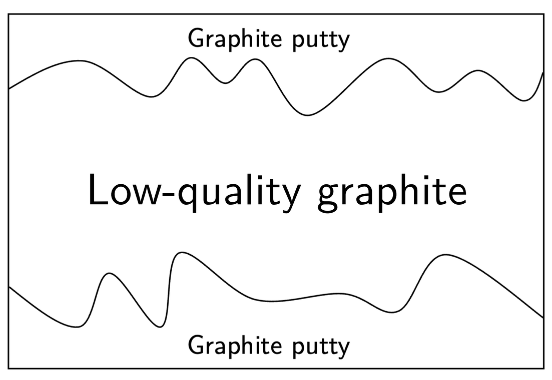
Low-quality (Regenerated) $0.7/kg	Mid-quality (Formed) $1.5/kg	High-quality (Molded) $3/kg

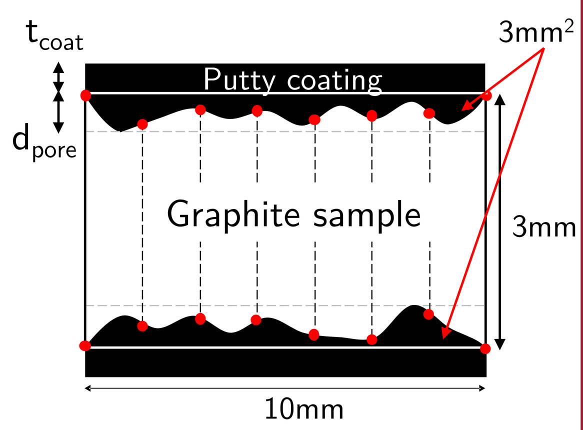
Laser flash analysis for high-temperature thermal diffusivity measurements

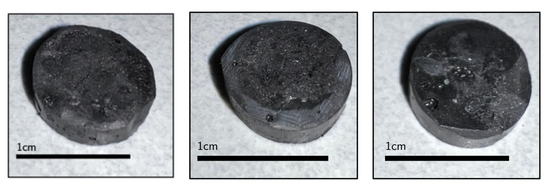




Roughness ~0.5mm (SEM)
LFA requires flat samples
⇒ coating required

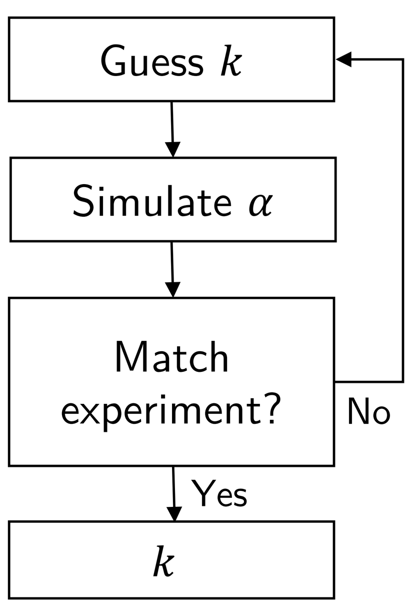


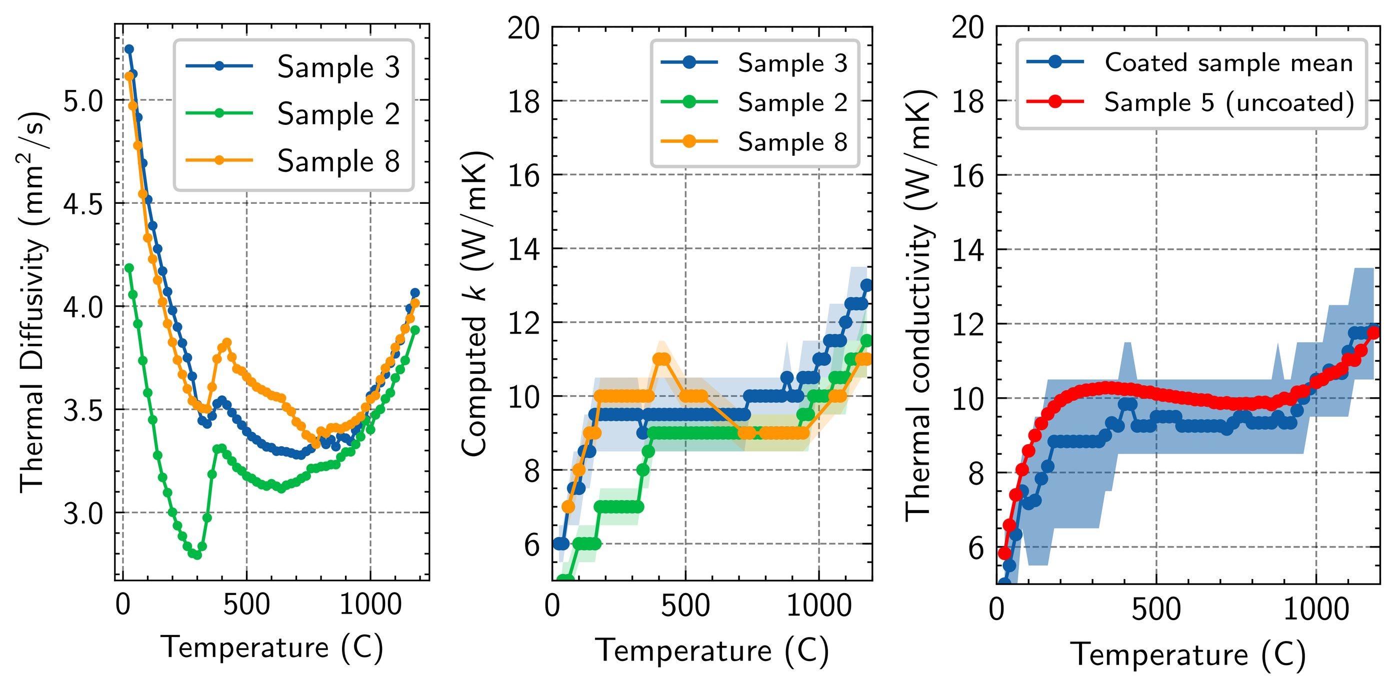




Generated 100 sample geometries for α simulations

How to back-calculate k from coated sample?



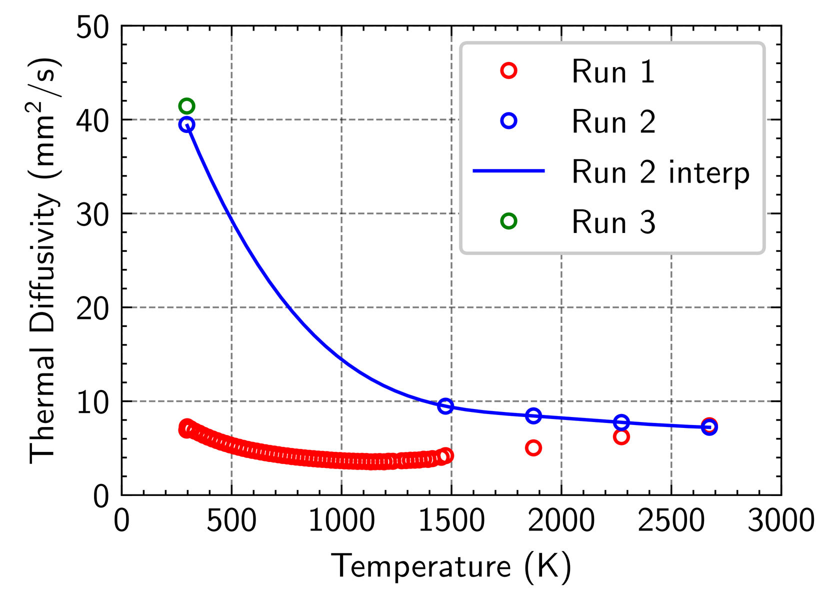


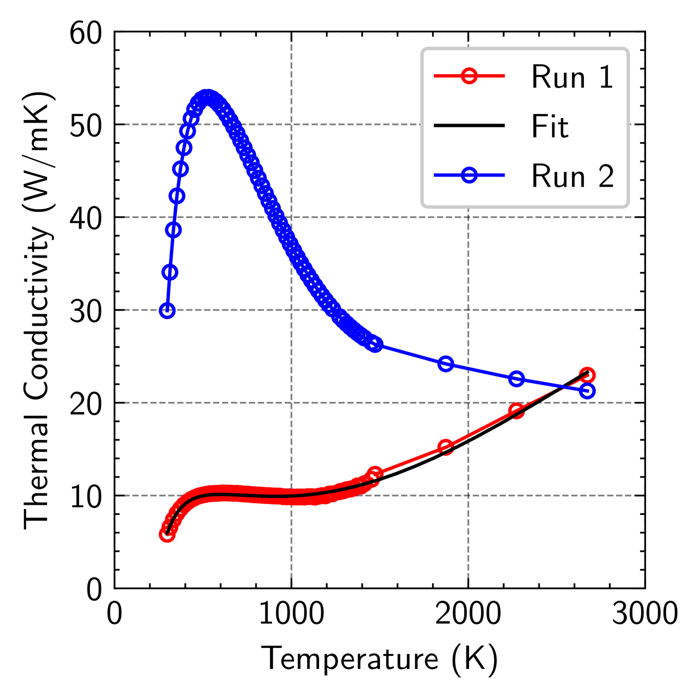
Analysis shows k is ~10 W/mK at 1000°C, seems to increase at high temps

Measurements above 1200°C with uncoated samples

Putty pyrolyzes above 1200°C

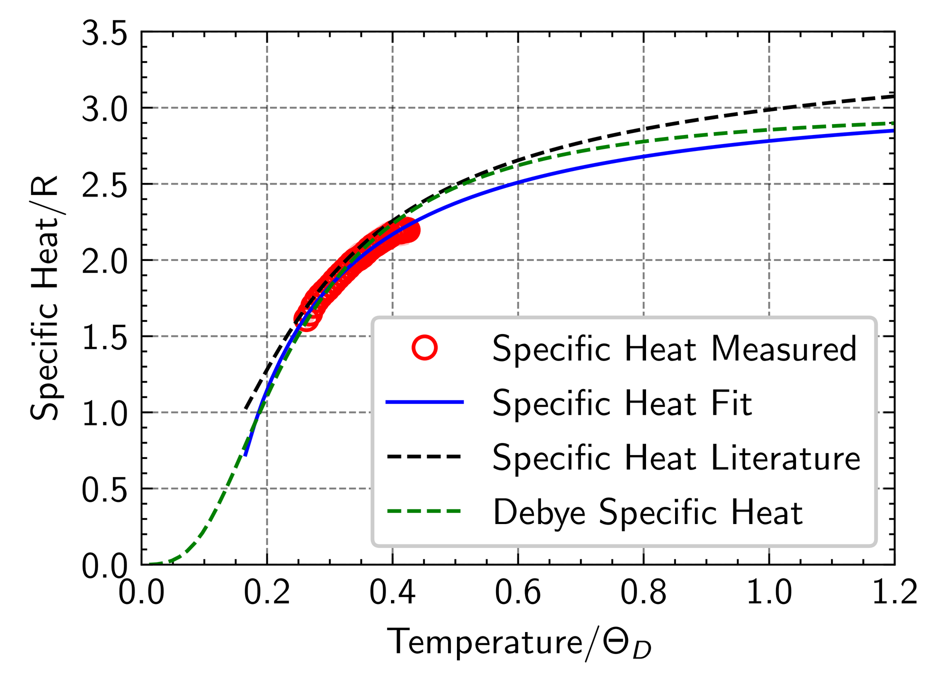
Use best uncoated graphite samples





Agreement with putty coated measurements at low temps.

Local maximum in thermal conductivity at ~225°C



High Debye temperature of graphite (1800K) means c_p rises slowly

Why does k increase above 1000K in Run 1?

Is it photon diffusion? $k_{\text{photon}} = \frac{16\sigma n^2 T^3}{3\beta}$

Maxwell-Eucken EMT: $k_{\text{eff}} = \frac{k_C v_C + k_{\text{air}} v_{\text{air}} \frac{3k_C}{2k_C + k_{\text{air}}}}{v_C + v_{\text{air}} \frac{3k_C}{2k_C + k_{\text{air}}}}$

Based on graphite density,
$v_C = 0.7, v_{\text{air}} = 0.3$
$k_C \approx 20, k_{\text{air}} \approx 0.1$

Photon diffusion would increase k_{air}. However, calculations show only a 10-20% increase in k_{eff} at high temperatures due to photon diffusion.

Analysis shows k is ~20 W/mK at 2000°C, due to sintering effects

We have measured thermal conductivity of low-quality graphite at high temperatures

- Low-quality graphite has macro-scale pores, so **flat surfaces are difficult to obtain**, but are required for LFA thermal diffusivity measurements
- At temperatures **below 1200°C, a putty coating was used** to create flat surfaces
- A methodology was developed to extract the thermal conductivity of the coated low-quality graphite, indicating a **thermal conductivity of 10 W/mK at 1000°C**
- **At higher temperatures,** the putty coating pyrolyzes, so **uncoated graphite was used.** Measurements were compared to coated graphite to ensure accuracy
- **Thermal conductivity of 20 W/mK at 2000°C** was obtained. Increase in conductivity at higher temperatures was attributed to sintering effects.

Acknowledgements and References

We thank Bruno Hay and Olivier Beaumont at LNE for taking the high-temperature thermal diffusivity measurements of uncoated graphite.

We additionally thank Gang Chen, Alessandro Turchi, and Bernd Helber for useful discussions on thermal conductivity measurement and analysis techniques.

Data, code, geometry files, and COMSOL files are available on GitHub.[7]

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