ABSTRACT

Blackbody radiation is the name given to the phenomenon that makes warm objects radiate—it explains why a hot stove glows red, or why the sun is so bright. This radiation is well-understood in physics, but some theories of new particles suggest that at low temperatures there will be small deviations to the equations that normally predict the amount of power radiated by these bodies. I am conducting an experiment designed to search for these deviations. This experiment will involve measuring the radiated microwave power from a resonant cavity and a resistor as they are cooled to liquid nitrogen temperatures; standard physics predicts these power values scale linearly with temperature, which is the expected result. However, some expanded standard model theories predict a deficit of power at low temperatures due to mixing of photons with new light particles. This research will help refine our understanding of blackbody radiation at low temperatures, including our understanding of the results from the UW Axion Dark Matter eXperiment (ADMX).

THEORY

Blackbody radiation is a major source of noise for precision physics experiments and quantum computing. Standard electromagnetism predicts a linear relationship between radiated power and temperature at a given frequency, but the evaluation of blackbody radiation, also called thermal radiation, is well understood in physics, but some theories of new particles predict deviations from standard blackbody power at low temperatures due to mixing of photons with new light particles. This research will help refine our understanding of blackbody radiation at low temperatures, including our understanding of the results from the UW Axion Dark Matter eXperiment (ADMX).

EXPERIMENTAL SETUP

We study an arrangement of a resonator, circulator, and low-noise amplifier common to experiments like ADMX, Project 8, and superconducting quantum computing readout while different components are cooled cryogenically. We measured the noise output of the experimental apparatus in order to gain a baseline for comparison using the equation

\[ P = G_b k T_{amp} + P_{other}. \]

In which:
- \( P \) stands for the power output of the experimental apparatus
- \( G \) stands for the gain of the amplifiers
- \( b \) represents bandwidth—the range of the frequencies over which the power is measured
- \( k \) is the Stefan-Boltzmann constant
- \( T \) is the temperature; the subscript “amp” refers to the amplifier, while “other” captures thermal noise

We rearranged this equation for power measurements at both room temperature and liquid nitrogen temperature. This gave us

\[ P_{RT} = \frac{T_{amp}}{T_{RT}} P_{amp} + P_{other}, \]

\[ P_{LN} = \frac{T_{amp}}{T_{LN}} P_{amp} + P_{other}. \]

The subscript “RT” is for room temperature, while “LN” is for liquid nitrogen.

We measured the power off-resonance to be -114.0 dBm/Hz at 300 K and -117.7 dBm/Hz at 77 K, giving us \( T_{amp} = 88.89 \) K.

RESULTS

Off-resonance, the radiated power is dominated by thermal photons emitted from the cavity. Off-resonance, the thermal photons from the terminator are reflected off the cavity and the primary source of power.

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