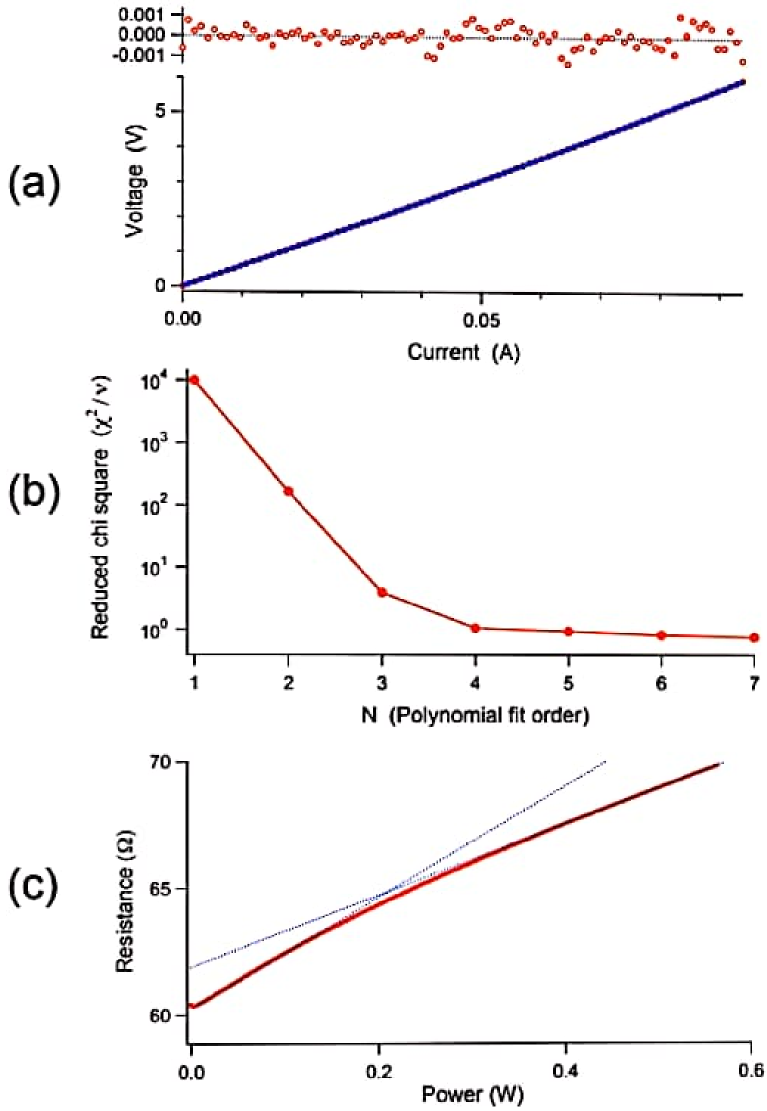

FIG. 5: (a) IV curve for the metal-film resistor. (b) Estimated standard deviation of curve-fit residuals vs. the number of terms N in a polynomial fit. (c) Resistance vs. power. Dotted lines are fits to local slopes at $P = 0$ and 0.5 W, giving $dR/dP = 22.1 \pm 0.2$ Ω/W and 14.22 ± 0.02 Ω/W, respectively. Plot at top of (a) shows fit residuals.

dissipation, the lamp's filament was red hot. The colour of a heated object is linked to its temperature approximately through a black-body relationship, and "red hot" corresponds to temperatures of 500-1000 °C [11]. Taking a temperature of 750 °C, we can try to estimate the resistance change from measured variations of the resistivity of materials with temperature. From standard tables of the resistance of platinum resistors, we see that the ratio of resistance at 750 $\pm$ 250 °C to that of 20 °C is 3.3 $\pm$ 1.2 [12]. This is consistent with the ratio of the lamp's resistance, 4.38 $\pm$ 0.05, as deduced from Fig. 4b: at $P = 0.5$ W, $R = 221 \pm 2\ \Omega$), while at $P = 0$ W, $R = 50.7 \pm 0.5\ \Omega$. It is not clear what metal the metal-film resistor uses. If we assume that its characteristics are similar to platinum, a resistance ratio of 69.0/60.4 = 1.14 corresponds to about 50 $\pm$ 5 °C. This is consistent with the qualitative observation that the metal film resistor was warm when dissipating $P = 0.5$W. Because the element is insulated by plastic, it is quite possible for it to be at 50 °C while the outside is only at about 40 °C.

In thinking more about the effect we observed in the metal-film resistor, we realized that our experiment had a flaw insofar as the analysis of the metal-film resistor is concerned. If there is a temperature rise that changes its resistance, we may expect a similar rise in the reference resistor, R_1. Indeed, since its nominal resistance is 221 Ω, we expect the effect to be more than three times as large! Thus, our inferences about the metal-film resistor are only qualitative. Because the reference resistor also warms and thus also increases its resistance, we expect the true effect to be *larger* than what we have measured. In any case, the main point remains valid, that ordinary resistors also show measurable deviations from Ohm's Law at modest power dissipations (0.5 W here). In retrospect, we could have eliminated the first resistor by programming the power supply to regulate current rather than voltage. The literature of the power-supply claims that the current would be accurate to 1% [6]. Any follow-up work should use this method.

Having argued that the difference between the behaviour of the lamp and of the metal-film resistor is linked to differences in temperature, we can now ask why the temperature of a lamp's filament varies so much while that of the metal-film resistor varies so little, even though the zero-power is similar and similar currents are passed through. The relation $P = I^2R$ implies that the same amount of power is dissipated; yet the temperature rise is quite different. An obvious difference between the two objects is that a lamp's filament is encased in a vacuum (or low-pressure) bulb while a metal-film resistor is encased in plastic. Since the