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TITLE: EXPERIENCE WITH A DOUBLE-COMPENSATING BEAM CALORIMETER

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EXPERIENCE WITH A DOUBLE-COMPENSATING BEAM CALORIMETER

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Summary

In an experiment to measure the D(t,α)n cross section at beam energies of 10 to 120 keV, we have developed a double-compensating beam calorimeter, based on a Swiss Design[1] to measure the particle beam intensity. A Faraday cup is not useful because of considerable charge exchange in the target gas at such low beam energies. We calibrated the calorimeter both with 10- and 3-MeV protons (comparing with a Faraday-cup measurement of the beam flux) and with the heat generated in a precision resistor. Both methods agree and give a calibration accurate to ±0.08% over a range of 10 to 800 mW beam power. Beam powers as low as 5 mW may be used, but with less accuracy. The beam energy must be known in order to calculate the particle intensity. Some difficulties with and peculiarities of the device are discussed.

Introduction

In an experiment to measure low-energy nuclear cross sections,[2-5] we have constructed a particle beam calorimeter based on a design[1] by Thomann and Benn of the University of Zürich, Switzerland. Our motive comes from the considerable charge exchange taking place in the 10- to 100-keV negative-charge deuteron and triton beams when passed through our gas targets (usually deuterium). The charge exchange precludes the use of a conventional Faraday cup to measure the beam current.

Our system is similar to the Swiss unit in physical and electronic design but differs in that we use a larger device, a different calibration method, and very low input-beam powers. We find that we can measure the beam power to an accuracy of ±0.08% over a range of 10 to 800 mW. The energy of beams with a power from 5 to 10 mW can be measured with less accuracy, around 1%.

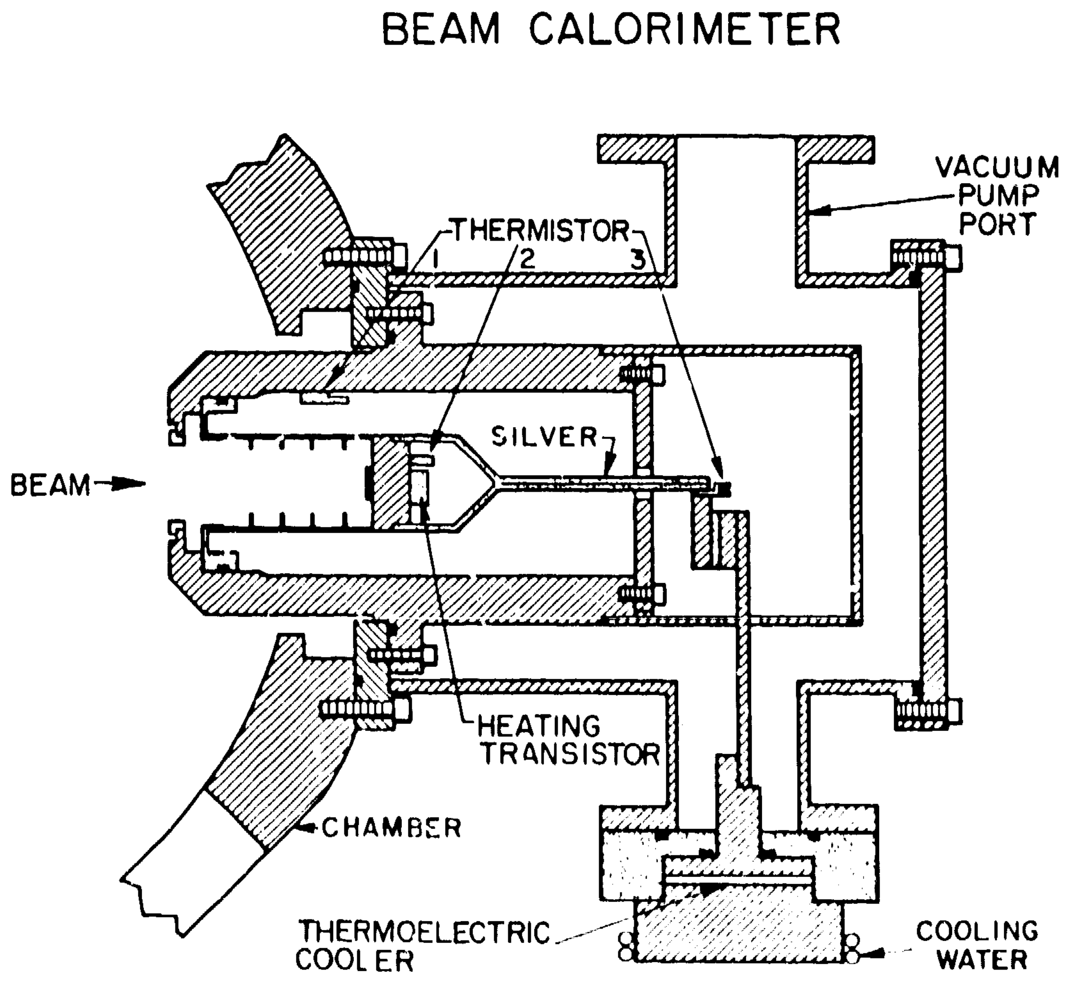

Fig. 1. Cross section diagram of the calorimeter. The size can be obtained noting that the entrance aperture is 2.5 cm in diameter. The silver bands and plastic parts are stippled. The cross hatched parts are copper except for the chamber (aluminum) and the outer vacuum case (steel).

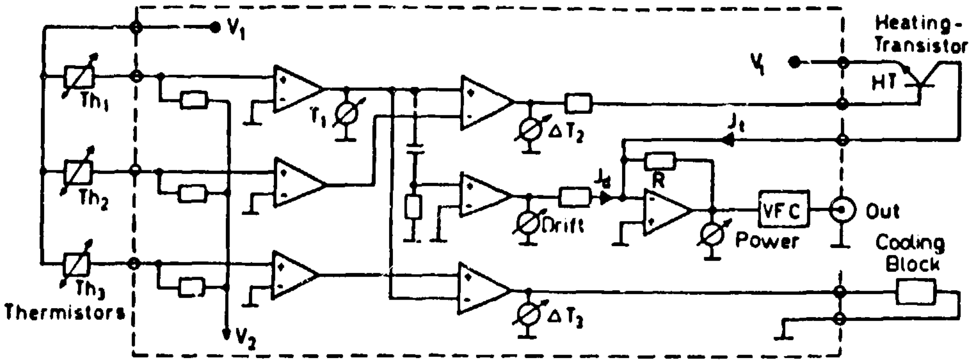

Fig. 2. Block diagram of the electronics. The elements with a single-headed arrow are meters and those with double-headed arrows are thermistors. Elements outside the dashed line are in the physical calorimeter.

Method

The basic method is the following. The beam is captured by a tungsten disc in a copper cup (see Fig. 1). The cup is electrically insulated to act as a Faraday cup for calibration purposes. Heat from the cup flows down silver bands to a Peltier thermoelectric cooler, a Cambion Model 801-3965-01. The heat flow is monitored by thermistors #2 and #3; a 25K temperature difference across the silver bands is kept precisely constant. The cup is kept near the temperature of the heavy copper body of the calorimeter by compensating the cooling with heat from a Motorola 2N5191 transistor. In actual practice the temperature of both the cup (T_2) and cooling block (T_3) are referred to the temperature of the copper body (T_1). A block diagram of the electronic circuit that controls T_2 and T_3 is shown in Fig. 2.

When a beam strikes the beam cup, the circuit compensates by reducing the heating current in the heating transistor. We then integrate the time history of the transistor power to get the total beam energy deposited. To facilitate this, the transistor current (J_t) is converted by a reference resistor (R) and a voltage-to-frequency convertor (VFC, Analog Devices Model 450K) into a sequence of logic pulses, the frequency of which is proportional to the supplied power. The thermistor resistances are converted to voltage signals with a modified bridge circuit, and the T_2 and T_3 voltages are compared with the T_1 voltage using high gain operational amplifiers; the resulting difference signals drive the heating transistor or the Peltier cooling block, respectively. In addition, the differential dT_1/dt produces a "drift" current (J_d) that is subtracted from the heating transistor current. This current compensates for the extra heat left in the beam cup by way of its heat capacity due to a drift in T_1. The electric circuits were well ventilated to prevent error due to large temperature changes of the electronic circuit elements.

Our device has a beam-cup diameter of 2.54 cm (compared with the 1-cm Swiss model), and a heat capacity of the beam cup of 46 J/K, which is about five times that of the Swiss unit. The time constant of the beam cup is about 20 sec (Swiss: 5 sec) and was determined by the size and heat conductivity of the base of the cup. The thermal time constant of the cooling (T_3) circuit is about 4 min; again this is determined by the heat flow in the materials. The drift-circuit electronic time constant is 7 sec. Studies were made to determine the gain settings in the different circuits that would give the most sensitive and accurate operation without the system going into oscillation. We covered the calorimeter itself with several centimeters of insulation, but the unit was not thermally insulated from the scattering chamber.

We can observe a short term temperature change of 2 mK (milliKelvin) in the calorimeter body (T_1), and can take account of values of dT_1/dt as small as 3.7 μK/sec. We feel our drift correction is accurate to about 15% giving a lower limit of error of ±30μW, the same as in the Swiss unit (see below)

Calibration

We used two methods of calibration. We used a particle beam, as did Thomann and Benn, to compare with Faraday cup current integration. We first used a 10-MeV and later a 3-MeV proton beam with a Brookhaven Model-1000 current integrator that was calibrated to ±0.05%. Secondly, we attached to the cup a precision 5000 ±0.005% Ohm (1 ppm temp. coeff.) resistor to the beam cup, and with a 4-wire connection, measured the voltage across the resistor when it was being used as a heat source. The resistor heat source, besides providing a calibration, was invaluable in the study of the overall response of the calorimeter. The result of the calibration is shown in Fig. 3. The two methods are in excellent agreement and gave a calibration constant $\mathcal{R}$ of 97.80 ± 0.08 microJoules per output pulse over a range of 10 to 800 mW. With care the calorimeter is usable in the range of 5 to 10 mW with an accuracy of 1%. The unit is limited on the high power side by the maximum output of the cooling circuit and at very low powers by fluctuations of the beam-off baseline. These results agree with the experience of Thomann and Benn who state an accuracy of ±0.07% ±30μW. A detailed discussion of the internal error contributions is given in Ref. 1 and is generally valid for our unit except that our chamber was not filled with hydrogen and ran with a vacuum of 10^{-6} Torr. Most of our experimental runs were longer than 30 min, and we found, as did Thomann and Benn, that error due to fluctuations of the beam intensity was insignificant.

Results and Suggestions For Improvement

With care, our calorimeter gives consistent and reliable results, measuring the deposited energies of beams of a few microamperes in the range of 10 to 120 keV, with an error of less than 0.1%. Since we also measured the beam energy to less than ±30 eV, the contribution to the final absolute error (∿1.4%) of the measured[2-5] $D(t,\alpha)n$ cross sections was small even at the lowest bombarding energy of 12.5 keV. Our greatest problem was that the device could be very tempermental when there were fast temperature changes in the ambient air temperature and of the cooling water. These fast drifts would cause the feedback circuits to become unstable. On a chart recorder we monitored the time history of the values of the output

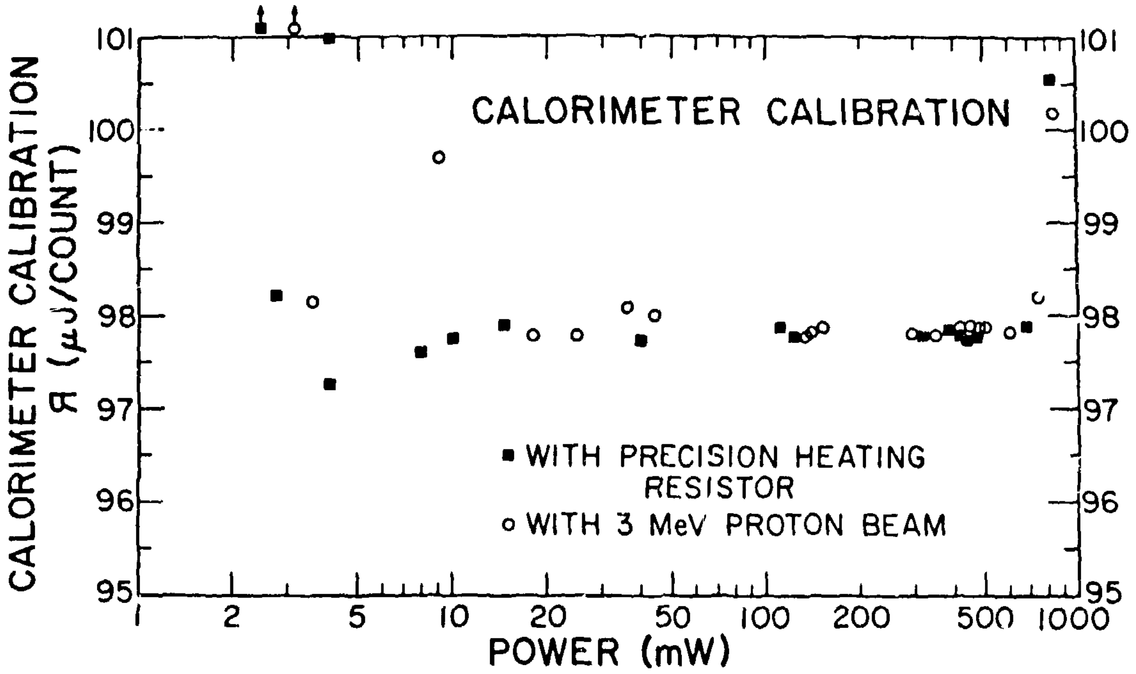

Fig. 3. Chart of the calorimeter calibration, Я, vs the power deposited in the calorimeter.

frequency, the cooling circuit temperature T_3, and the copper case temperature T_1 to observe any unstable operation. If we wished to have greater sensitivity and reliability for lower powers, the main improvement to the system would be to thermally insulate the unit from the scattering chamber, to improve the insulation of the case from the ambient air, and to stabilize the cooling water temperature. In addition, the calorimeter control circuit could be rebuilt to accommodate lower powers by using a larger reference resistor and a smaller heat flow to the Peltier cooler. The Swiss paper gives additional suggestions for improvements.

We constructed our gas target system so that it was electrically insulated, hoping that with careful secondary electron suppression the sum of the gas target and Faraday-cup electric currents would give a good measurement of the particle intensity. We did not succeed in this attempt. The sum of the currents gave a particle intensity that varied by ±5% with small changes in the suppression bias, when the beam had minor fluctuations in direction and intensity or changed in energy. This result verified our need for the calorimeter.

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