INSTITUTE OF PHYSICS PUBLISHING MEASUREMENT SCIENCE AND TECHNOLOGY
Meas. Sci. Technol. **14** (2003) 1–5 PII: S0957-0233(03)59312-2

Accurate determination of background scattered electrons in crossed electron– and gas–beam experiments using a movable gas beam source

M Hughes, K E James Jr, J G Childers and M A Khakoo

Department of Physics, California State University, Fullerton, CA 92834, USA

Received 6 February 2003, in final form 8 April 2003, accepted for publication 15 April 2003
Published
Online at stacks.iop.org/MST/14/1

Ascii/Word/MST/mst159312-xsl/PAP
Printed 30/4/2003
Issue no
Total pages
First page
Last page
File name E .TEX
Date req
Artnum
Cover date
(Ed: LAURET)

Abstract
We present the design and application of a movable collimated gas source of atomic and molecular species that allows the accurate determination of background-scattered electrons in beam–beam, low-energy electron scattering experiments. Our method provides a very simple solution for accurate background determination without using conventional 'choppers' or background gas-shunt lines. Further, it is more robust than existing conventional methods and extremely practical.

Keywords: movable nozzle, electron scattering, background determination, servo-motor controller

1. Introduction

In an electron–gas beam–beam collision experiment, a collimated electron beam scatters from a collimated atomic or molecular beam in a vacuum apparatus; a detector is used to collect the scattered electron signal at a selected angle. However, the scattered electron signal also contains electrons scattered from the residual gas in the vacuum chamber as well as secondary electrons produced by electron scattering from metal surfaces of apparatus in the vacuum chamber and the chamber itself. Two popular methods have been developed to determine the amount of background scattering in such crossed-beam experiments. In each, the gas beam generated by the collimating structure (tube or capillary array) is blocked from entering the collision centre without changing the amount of static background gas in the chamber. These methods are the following.

(a) Using a beam flag ('chopper') placed just outside of the electron beam, near the collision centre, which reflects the gas beam away from the interaction region. This method is very simple to implement, but suffers from introducing an additional large surface close to the collision region. This surface acts as an additional source of secondary electron scattering. Whereas this may not be a problem in determining the background around discrete, gas-related inelastic spectral lines, it is a problem when determining contributions to elastic or continuum scattering from non-gas-related sources. Adding this flag also requires the nozzle of the gas source to be displaced further from the collision region, resulting in a loss of signal. Further, the introduction of a large surface close to the electron–gas beam collision region will have the tendency to produce a significant variation in the distribution of equipotentials at the collision region. This can lead to pernicious electron beam deflecting effects, which further reduce the possibility of determining background elastic or continuum electron scattering in the experiment. Choppers can be used if properly shielded (e.g. in Register *et al* 1980), but this means that the source has to be moved even further back from the interaction region, resulting in an increased loss of signal.
(b) Blocking the gas beam from exiting the collimating structure and shunting it into a side 'leak' in the vacuum chamber. Provided the gas flow-rate is not changed, this method provides an excellent way of measuring the true non-gas-related scattering background in the experiment. However, it has a major disadvantage—when the gas is shunted, the effect of changing conductivity in the gas flow system and the presence of dead volume(s) in

the system lead to transient gas pressure changes in the vacuum chamber. Such changes can cause the electron beam to fluctuate. Over many such cycles, this can generally lead to a deterioration of the electron beam stability unless differential pumping of the filament is used. Additionally, the gas switching from the target to background involves a gas-flow settling time that can be as large as several minutes. This leads to a loss in duty cycle of the experiment.

In this paper we present a simple, but very effective way of determining the background contribution without having to incur the problems of (a) and (b). Our method involves moving the target beam source in and out of alignment with the electron beam. The implementation of the movable source method is demonstrated with electron scattering from He.

2. Experimental details

2.1. Movable gas beam control

Figures 1(a) and (b) show details of the servo-motor and gas source assembly. The present source was used for conducting atomic hydrogen to the collision region (see Paolini and Khakoo 1998), but will also easily work for regularly stable gases. The servo-motor (Airtronics Incorporated, which delivered ≈20 oz-in of torque and required ≈200 mA of electric current) is mounted in a vacuum-sealed aluminium box. The vacuum seal at the 3/16 inch diameter shaft coupled to the motor is maintained via a Viton^{TM} O-ring lightly lubricated with Apiezon (K J Lesker Company) grease. The shaft is held onto the servo-motor using a tightly fitting pin that diametrically penetrates the motor and the mechanical coupler. Operating the servo-motor requires three electrical connections: (i) a power line at 5 V dc (V_{cc}), (ii) a source of positive pulses (+V_{cc} high/0 low) of controlled width and (iii) a ground return. If a larger torque is required, a separate 8 V power supply may be connected to the dc power line of the servo-motor in place of the 5 V V_{cc} line. These lines are fed into the aluminium box via a home-made electrical feedthrough comprised of three 0–80 screws separately glued through the lid of the box using vacuum-compatible ceramic-type epoxy (The Dexter Corporation). The lid was screwed into place and vacuum-sealed using Viton^{TM} gasket material of 1/32 inch (=0.08 mm) thickness. A Teflon^{TM} ring further up the shaft provides a precision bearing that prevents the shaft from rocking more than 0.1 mm. Using this system, we were able to obtain background pressures in the vacuum chamber of around 1×10^{-7} Torr with the system at about 120 °C.

The motor controller can be operated using a single signal line from the computer. The nozzle is placed in the aligned position by outputting a negative-going 5 V to ground level pulse for a period of 0.5 s and in the other position using a similar negative-going 5 V to ground level pulse for a period of 6 s or greater. To prevent an intermittent magnetic field produced by the electric current during motor operation, it was switched off after reaching either position using a relay system operated by a one-shot LM555 integrated circuit. The servo-motor is located well away from the electron beam path so that the small permanent magnetic field of the motor (measured to be <2 mG) does not affect the beam at any position of the spectrometer. A diagram of the operating electronics is shown in figure 2. We note that there are many other ways to setup this control circuit using different control line levels. Using this setup, the nozzle could be accurately (based on the servo-motor resolution, ≈0.2 mm) placed in and out of the collision region.

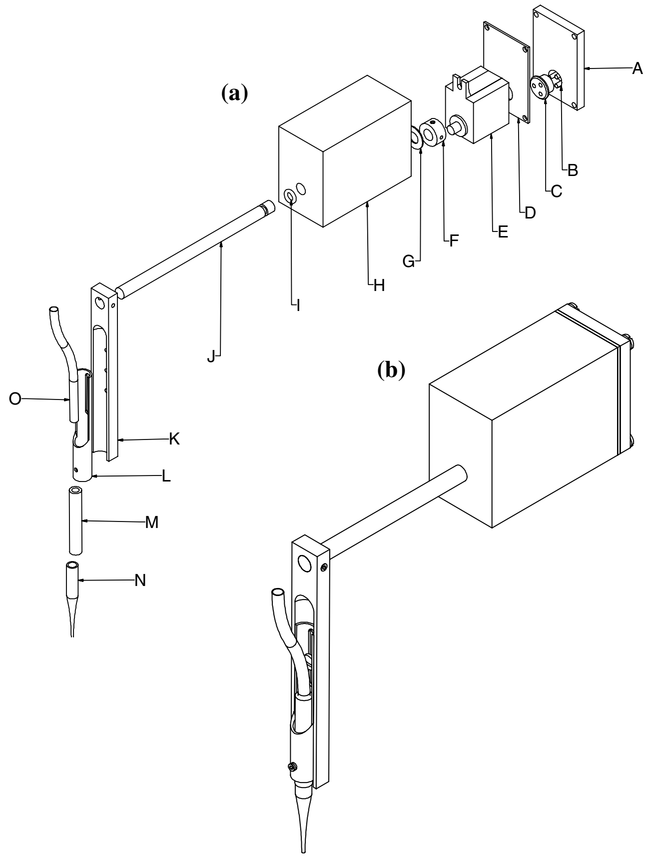

Figure 1. Diagram of the vacuum-isolated servo-motor assembly used to move the source. (a) Exploded view and (b) assembled view. Legend in (a): **A**: top flange of vacuum box; **B**: 3-pin electrical feedthroughs (0–80 screws) epoxied into Delran^{TM} insulation (**C**) in turn epoxied into **A**; **D**:1/32 inch Viton gasket; **E**: servo-motor with retaining screw slot; **F**: mechanical coupler from servo-motor shaft to main drive shaft **J**; **G**: Teflon^{TM} washer to reduce friction between **F** and vacuum box **H**; **I**: O-ring forming seal between **H** and **J**; **K** and **L**: supports for needle mounting; **M**: cylinder for grounding needle and allowing Teflon 'spaghetti' tube **O** to mate with outside of **N**; **N**: glass tube which is silver-painted outside and then outside-sooted. Teflon tube **O** conducts gas from outside (see Paolini and Khakoo 1998). Not shown: a Teflon bearing (1/4 inch ring in an L-support attached to **H**, to precisely support shaft **J** at about 3/4 inch from the end of **H**). The servo-motor defines ϕ (see figure 3).

2.2. Background determination

A geometric detail of the setup is shown in figure 3. The incident electron beam was about 1.5 mm in diameter and crossed the gas target about 5 mm downstream of the gas-collimating nozzle. The tip of the gas jet was moved (from its aligned position) a distance of approximately 10 mm to one side of the electron beam (the gas beam not-aligned position) in a direction perpendicular to the electron beam. To ensure that the electron beam was not scattering from the needle, energy loss spectra from zero energy loss (elastic scattering) up to

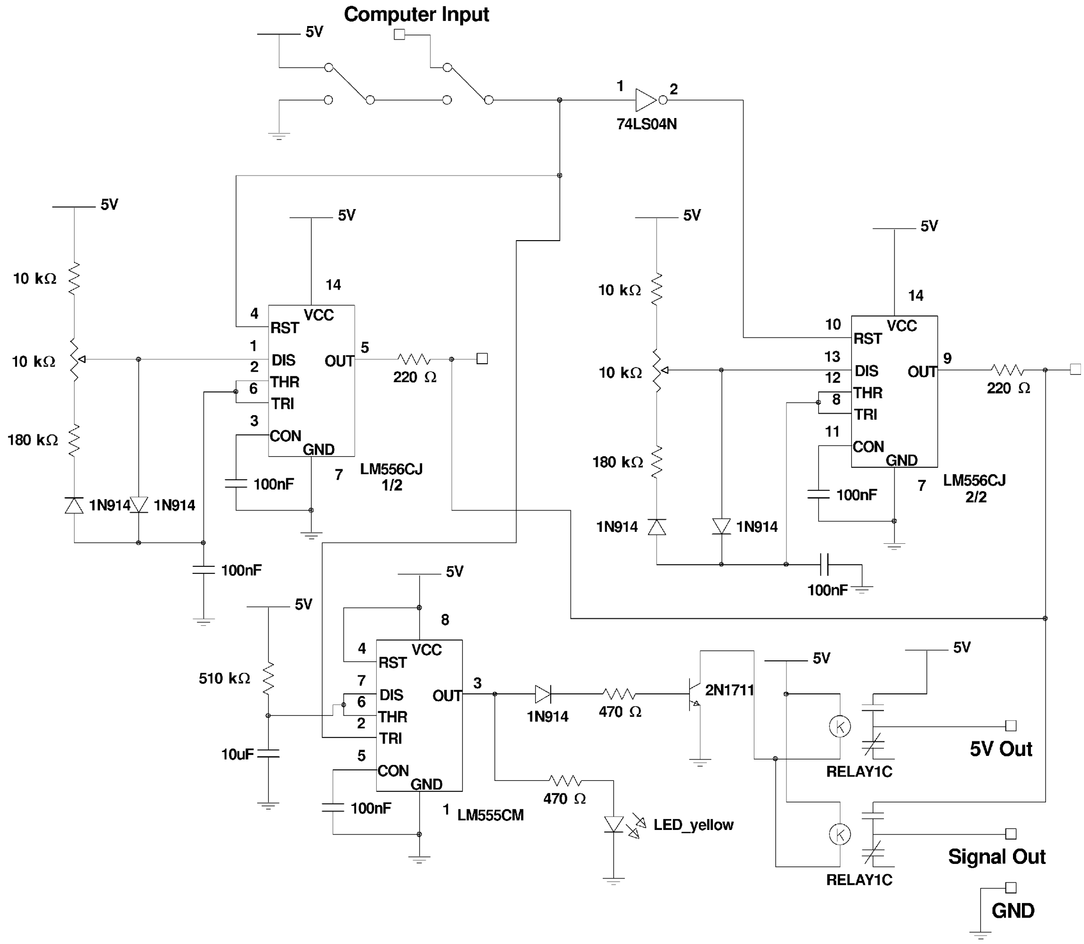

Figure 2. Electronics circuit diagram of the motor drive controller.

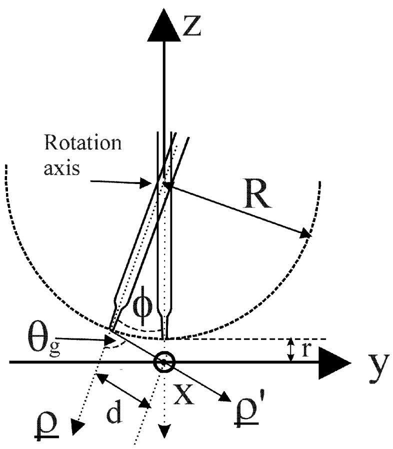

Figure 3. Geometric details of the setup of the gas nozzle with respect to the electron beam. The x-axis ($\odot$) points out of the page. For explanation of symbols see text. $\underline{\rho}$ is the direction of the forward gas beam and $\underline{\rho}'$ the direction of the gas overlapping the electron beam.

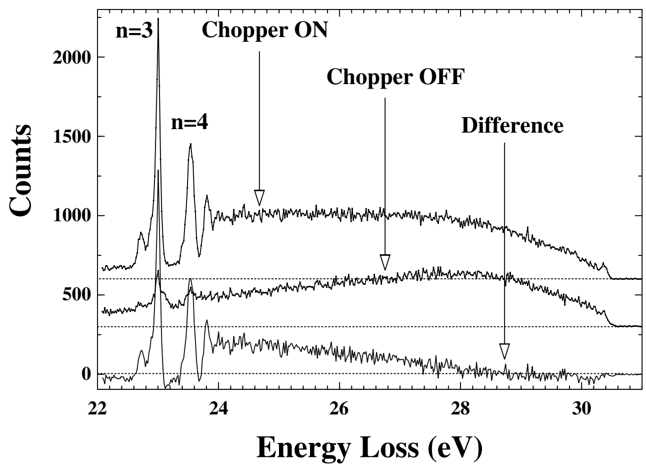

Figure 4. Typical spectra of He taken using a gas beam chopper system taken at $E_0 = 30.6$ eV and $\theta = 20°$, with the chopper about 4 mm from the collision centre and the nozzle placed 1 mm behind the chopper. ON corresponds to gas not blocked by the chopper, while OFF corresponds to the gas being blocked by the chopper. The ON and OFF spectra have been offset from the difference spectrum for clarity, but the corresponding baselines are dotted in. Note that the subtracted spectrum (ON–OFF) yields negative counts, indicating the secondary scattering signal introduced by the chopper.

the maximum energy loss ($=E_0$, the incident electron energy) were taken with no gas exiting the gas beam nozzle.

Typical spectra (of He in this case) using a conventional 'chopper' are shown in figure 4. Spectra taken with the movable source with no gas present are shown in figure 5 and with He flowing in figure 6. From these three sets of spectra we make the following observations.

(i) The chopper setup gives rise to a secondary source of scattered electrons, resulting in *negative subtraction*

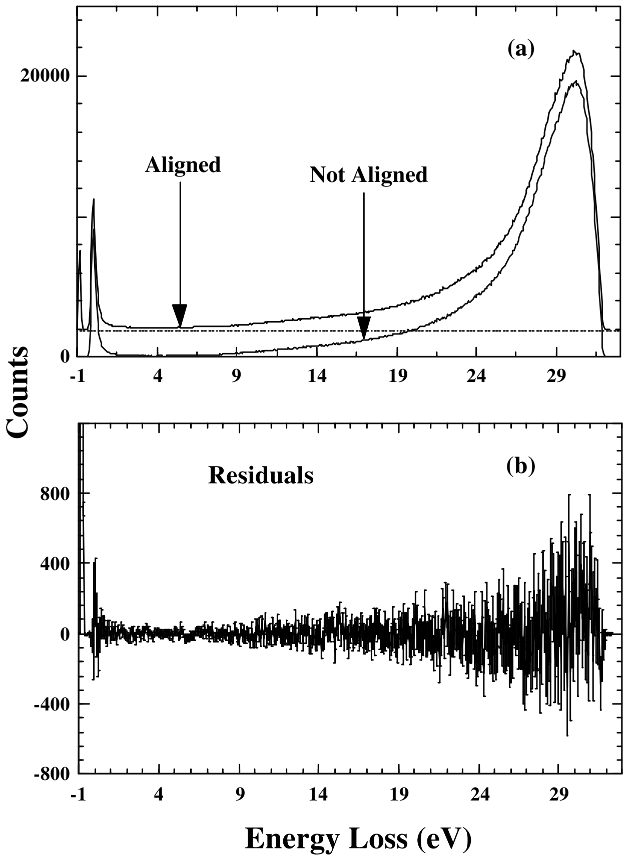

Figure 5. Energy loss spectra taken with no gas flowing through the nozzle at $E_0 = 31.7$ eV and $\theta = 21°$. (a) Gas beam in place (aligned) and displaced away (not-aligned). In the not-aligned position, the nozzle was rotated to $\phi \approx 6°$. The aligned spectrum is offset from the not-aligned spectrum, but its zero baseline is dotted in. (b) The difference between aligned and not-aligned. At maximum (at 31 eV energy loss) this difference is only ≈0.5%.

spectra when the chopper ON and chopper OFF spectra are subtracted.

(ii) Figure 5(a) clearly shows electrons scattered from residual gas (elastic peak at 0 eV energy loss and smaller contribution at higher energy loss) and secondary electrons produced by electrons scattering from metal surfaces (whose largest contribution is at higher energy loss). The difference between the two spectra, shown in figure 5(b), demonstrates that this technique eliminates both sources of unwanted electrons and that the nozzle tip does produce a small, but negligible, contribution of secondary electrons. As can be seen, there is very little difference between the two spectra. Maximal differences are observed in the limiting energy loss region around E_0. However, these were less than 0.5%.

(iii) With gas flowing (He in this case) we are now able to measure spectra with accurate background corrections. Spectra of He taken at both low and high scattering angles are shown in figure 6. When the gas beam aligned and not-aligned spectra are subtracted, as shown in figures 6(a) and (b), we obtain spectra from gas-related scattering only. This is evident from the averaged zero baselines around the discrete peaks, but is also true in the continuum region. This method therefore allows the accurate background correction of continuum or broad energy loss structure, such as ionization continua, resonances or molecular bands. We note that the spectra in figures 4–6 should be corrected for the transmission characteristic of the scattered electron detector, but that is a separate problem from the determination of the background scattered electron signal.

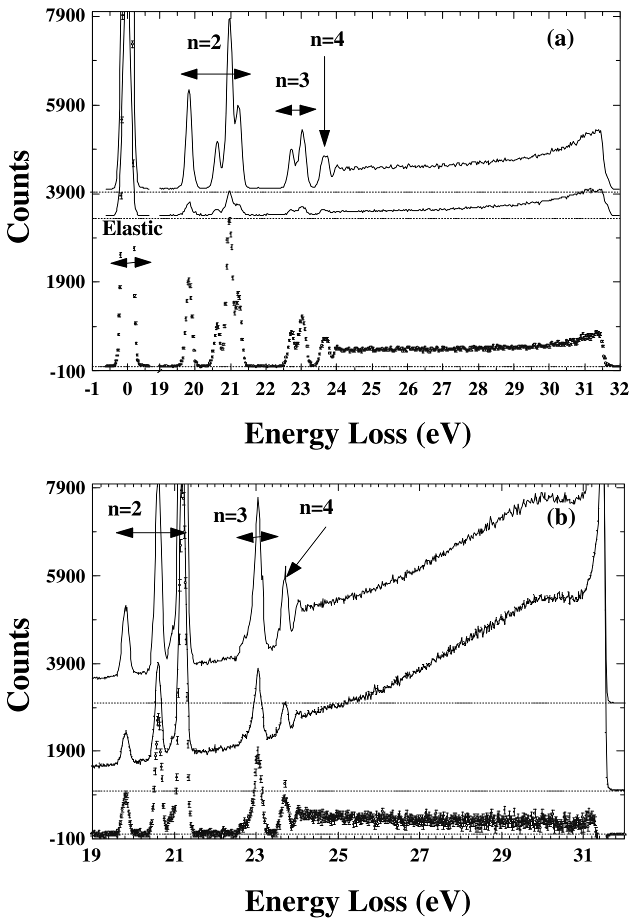

Figure 6. Spectra of He (a) at $E_0 = 31.7$ eV and the scattering angle of $\theta = 90°$ and (b) taken at $E_0 = 31.5$ eV and the scattering angle of $\theta = 20°$. In both figures, the upper spectrum is with the nozzle aligned (signal + background), the middle spectrum is with the nozzle not-aligned (background, with the nozzle at $\phi \approx 6°$) and the bottom spectrum is signal + background minus background. The upper and middle spectra have been offset for clarity, but their zero baselines are dotted in. Note the zero counts between the inelastic peaks in the bottom spectrum. Note also the positive counts in the continuum of the bottom spectrum. Compare figure 6(b) with figure 4.

Note that the gas beam position can be optimized *in situ* for maximum scattering signal by a simple adjustment of the potentiometer controlling the alignment of the nozzle axis with the electron beam. We have also implemented this method for reactive gas species (atomic hydrogen: Paolini and Khakoo 1998, Childers *et al* 2003) to measure elastic, inelastic and ionization electron scattering processes.

2.3. Signal to background considerations

From figure 3, for a rotation angle ϕ of the source, the emission angle θ_g of the gas beam at the collision region can be derived

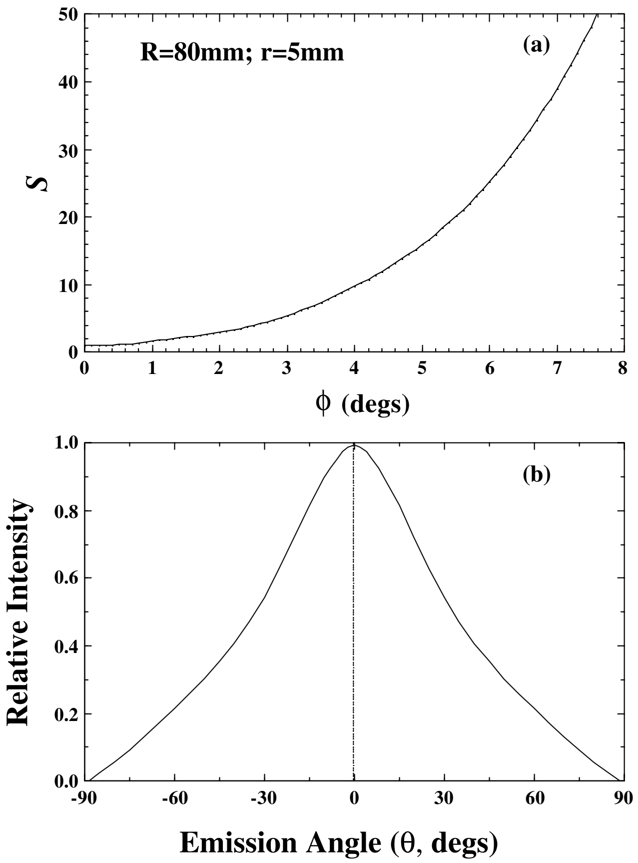

Figure 7. (a) Ratio of signal intensities S for values of $R = 80$ mm and $r = 5$ mm for atomic H gas. (b) Gas intensity profile derived using a Monte Carlo calculation (Roundy and Khakoo 2003), shown here for a 0.75 mm diameter nozzle of length 5 mm, used to calculate S. The Monte Carlo algorithm used a hard sphere diameter for H of two Bohr radii.

as

$$\theta_g = \tan^{-1}\left[\frac{\sin\phi}{\cos\phi - R/(R+r)}\right] \qquad (1)$$

and

$$d^2 = (R+r)^2 + R^2 - 2(R+r)R\cos\phi, \qquad (2)$$

where r is the closest distance of the nozzle tip from the collision centre ($\phi = 0$; ⊙ in figure 3) and R is the radius of rotation of the nozzle tip. From these considerations, the beam intensity ratio S at the collision region can be determined to first order, neglecting the spatial extent of the electron beam, as

$$S = \frac{I(0)/r^2}{I(\theta_g)/d^2}. \qquad (3)$$

Using a Monte Carlo gas beam profile calculation developed in our laboratory (Roundy and Khakoo 2003) and combining equations (1) and (3), we can estimate S as a function of ϕ for fixed values of r and R. The dependence of S on ϕ for a typical geometry in our experiment is shown in figure 7(a). The profile $I(\theta)$ used to determine this S is shown in figure 7(b). Note that from equation (3), S becomes infinitely large as $I(\theta_g)$ goes to 0. From figure 7(b), this occurs at $\theta_g = 90°$. This condition is obtained from equation (1) when $\cos(\phi) = R/(R+r)$. For $R = 80$ mm and $r = 5$ mm (our experimental values), this occurs at $\phi = 19.8°$, which corresponds to $d = 28.8$ mm. Very large values of S can be observed for very small beam deflection angles (ϕ), even for the broad intensity profile of our short nozzle.

3. Conclusions

We have described an accurate method for the determination of background scattering in beam–beam experiments using a very easily constructed, compact and very economical piece of apparatus. The superiority of this method over more popular methods is that the nozzle has a surface area several hundred times smaller than that of a chopper, which significantly reduces the production of extra secondary electrons when the nozzle is aligned as opposed to not-aligned. This method also avoids the transient gas fluctuation effects present when the gas is shunted through a side leak. We expect this method to have applications for beam–beam collision cross-section measurements for a large range of processes.

Acknowledgments

The present work was funded by the National Science Foundation under Grant no NSF-RUI-PHY-0096808. The technical help of Hugo Fabris (electronics), David Parsons (machine shop) and Jorg Meyer (glass shop) are very gratefully acknowledged. We also thank Mr Michael T Kanik for his work on and recommendations regarding the use of servo-motors.

References

Airtronics Incorporated *94091Z Supermicrolite Servo Motor* 1185 Stanford Court, Anaheim, CA 92805, USA
Childers J G, James K E Jr, Hughes M, Bray I, Baertschy M and Khakoo M A 2003 *Phys. Rev.* A in preparation Q.1
Kurt J Lesker Company *Apiezon L vacuum grease* 1515 Worthington Ave, Clairton, PA 15025, USA
Paolini B and Khakoo M A 1998 *Rev. Sci. Instrum.* **69** 3132–41
Register D F, Trajmar S and Srivastava S K 1980 *Phys. Rev.* A **21** 1134–43
Roundy D and Khakoo M A 2003 *Meas. Sci. Technol.* in preparation
The Dexter Corporation *Epoxy Patch 1C* One Dexter Drive, Seabrook, NH 038745, USA Q.2

Queries for IOP paper 59312

Journal: **MST**
Author: **M Hughes et al**
Short title: **Accurate determination of background scattered electrons in crossed electron– and gas–beam experiments using a movable gas beam source**

Page 5

Query 1:

Author: Any update for Childers etal 2003 and Roundy and Khakoo 2003?

Query 2:

Author: Please supply a year for The Dexter Corporation work.