

Quantum Technology

PROGRAMME



TEACHER GUIDANCE

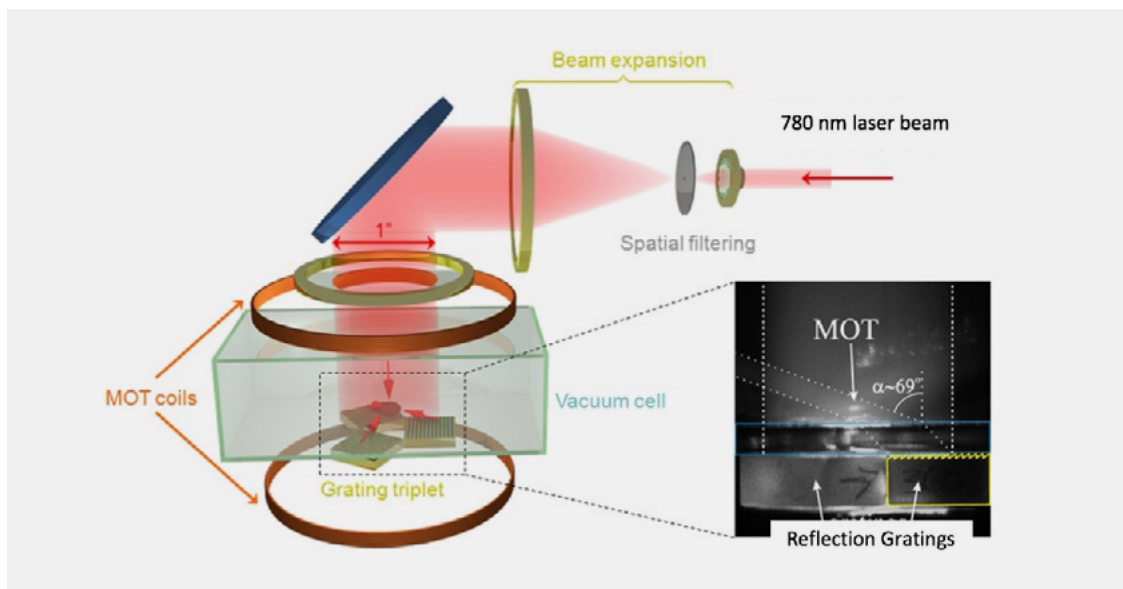
Exploring diffraction

1 BACKGROUND

In this activity we propose some useful ways to develop knowledge and understanding of the theory and practical applications of diffraction gratings. Moreover, by linking diffraction gratings with the cutting-edge work of the Quantum Technology Hubs, we aim at inspiring students to consider a career in quantum technology development. Students will be able to see that despite the inaccessibility of quantum physics often perceived by people, these concepts are not far removed from the students' current academic experience.

The Grating Magneto Optical Traps (GMOTs) developed at the [University of Strathclyde](#) (Glasgow), in partnership with [Kelvin Nanotechnologies](#), are an interesting step forward in achieving 'laser cooling' in more efficient ways. This will potentially lead to miniaturization of laser cooling technology, and hence of quantum sensors in general. In 'laser cooling' a minimum of four laser beams are focused on a relatively small number of atoms from different directions. The frequency of the lasers used is such that the photons' momentum will be transferred to the atoms trapped. As the laser beams hit the atoms from four (or six) directions, the atoms will slow down and almost completely stop vibrating. We call these 'cold atoms' because the temperatures reached in these optical atom traps are in the order of the pK.

The grating triplet at the base of the GMOT shown in the figure below enables the trap to use a single laser beam, split and steer it to the centre of the trap, where atoms can be slowed down to temperatures of 3 μ K. This removes the need to have multiple laser beams and/or mirrors, potentially reducing the time and complexity needed for calibration. For more information on how laser cooling is achieved see our 'Laser Cooling' activity.

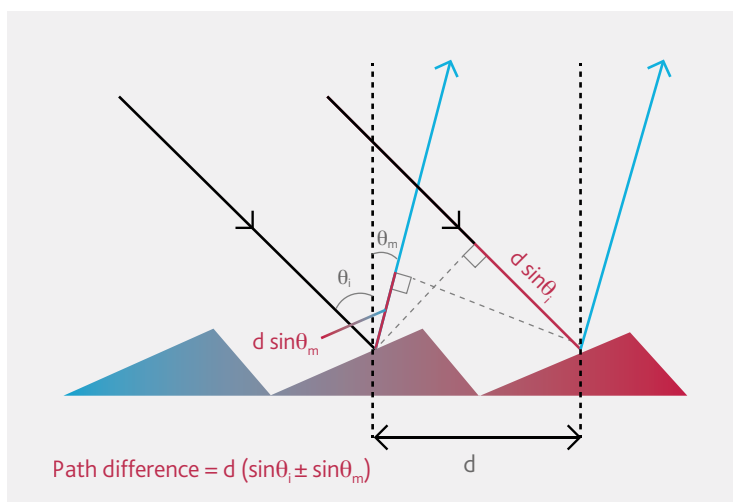


The GMOT coils generate a magnetic field changing in space which increases the probability of atoms drifting further away from the centre of the vacuum cell (trap) to absorb and re-emit red photons from the split laser beam. Thanks to this solution, when an atom moves away from the centre of the trap, its atomic resonance is shifted closer to the laser light frequency, so the atom becomes more likely to get a photon 'punch' towards the centre of the trap.

GMOTs are useful when we need to trap neutral particles, like Rubidium atoms, because these would not be affected by electromagnetic fields (as they are neutral). However, electromagnetic fields are commonly used in 'trapped ion quantum computers' to trap two charged atoms (ions) in a state of quantum entanglement to form q-bits, or quantum bits (more on quantum entanglement in our 'Quantum Computing' activity).

The diffraction gratings used in GMOTs are reflective diffraction gratings (see diagram to the right), analogous to a CD or DVD surface.

However, in this activity, students will use a transmission diffraction grating made of many slits per mm. This set-up makes it easier for students to collect accurate measurements.





2 OBJECTIVES

- ▶ Understand the principles of how diffraction gratings can be used in laser cooling
- ▶ Develop practical skills through diffraction grating practical work
- ▶ Develop knowledge and understanding of diffraction gratings and their applications

3 ADVANCED PREPARATION

Students should be given the following equipment:

- ▶ Laser pointer
- ▶ Diffraction gratings of known number of slits per mm and grating holder
- ▶ Screen
- ▶ Graph paper
- ▶ Clamps and stands (if needed)
- ▶ Diffraction grating of unknown number of slits per mm
- ▶ Feathers of different sizes and of different birds
- ▶ New £5 or £10 banknotes

4 INTRODUCTION

GMOTs use diffraction gratings to split and steer a single laser beam into three further beams. Where the four resulting beams meet, atoms of Rubidium are trapped and 'cooled' to temperatures of $3\mu\text{K}$.

In this activity you will explore how diffraction gratings work and understand how to apply the diffraction grating equation to measure the structures of common objects.

5 ACTIVITY

Students would benefit from having learnt about wave diffraction, interference and possibly the double slit experiment before completing this activity. They could be introduced to the equation for diffraction gratings in this lesson.

The PowerPoint will support the teaching and learning in this activity and guide the students in their investigations through probing questions. However, it is expected that the students conduct their independent practical task, so they should be encouraged to write their own method, collect their own data and consider the steps they need to obtain valid results.



6 PLENARY

Discuss the questions from the PowerPoint and compare students' results when finding the number of slits per mm from the unknown gratings and the distance between the barbs of the feather and/or distance between dots in the £5/£10 notes (Queen's chin).

A good demonstration to visualise the equation is to shine a red and green laser pointer through the same diffraction grating or diffraction goggles. If you can overlap the two patterns students should clearly see that the distance between maxima is greater for the red laser and lower for the green laser. This is because constructive interference occurs when the path difference is an integer number of wavelengths, and a maximum intensity is observed at angle θ $d \sin \theta = n\lambda$ and if λ is increased the angle θ must increase (for the same slit separation d).

7 EXTENSION

The core of the practical task proposed is to allow the students to use the diffraction equation to determine the slit separation d for an unknown diffraction grating. But if time allows the extension investigations to find the separation between dots in the Queen's chin on a £5/£10 note and/or the distance between the barbs in a feather are very effective ways to engage students into real applications of diffraction.

8 TEACHER INFORMATION

Students should be encouraged to plan their own procedure, but graph paper should be made available to them. This could be Blu-Tacked on the screen to help them read the distance between maxima (s) more precisely. If your lab has sufficient space, it is always better to have a good distance between the gratings and the screen, so a large diffraction pattern can be generated. However, some maxima might fall outside the screen for some diffraction gratings, so it is advisable to test the layout of this experiment before the lesson.

This activity is well suited to develop the skills needed in all specifications in England and Wales, as the diffraction grating practical is listed as one of the required practicals. In the Scottish curriculum this topic will fit well in the Particles and Waves section of the Higher Physics Course and in Northern Ireland this activity will develop the knowledge, understanding and skills of Unit 2 in the CCEA GCE Physics specification.

There are a number of health and safety considerations in this practical task, so we recommend you write your own risk assessment before the lesson, as each room is different. But some points to consider are:

- ▶ possible reflections from the screen (dark matt surfaces could be used, though the diffraction pattern will look dimmer)
- ▶ possible maxima that go off the screen (are any students standing in the way of potential maxima?)
- ▶ do not point laser beams at people's eyes and consider possible reflections
- ▶ the actual power rating of some laser pointers (especially key ring types) might not match the rating printed on the label and it could be higher. The recommended power for a laser beam for use in secondary schools is less than 1mW.

Some further health and safety suggestions can be found on the CLEAPPS website here: <http://science.cleapss.org.uk/Resource-Info/PS052-Lasers-laser-devices-and-LEDs.aspx>



9 LINKS TO FURTHER RESOURCES

Laser Cooling activity

10 ACTIVITY SHEETS

Use the PowerPoint to guide learners through the investigations proposed and to introduce diffraction gratings in the context of GMOTs Quantum Technology.

11 ANSWERS

The answers to the investigations will depend on the laser wavelength used, the diffraction gratings available to the school and the feathers or notes used, but it will be useful to compare data and methods with different groups within the class.

Some suggested points to emphasise for the questions on slide 12 could be:

- ▶ As students will obtain two maxima for each order (on either side of the central maximum), they should measure $2s$, the separation of the first orders either side, then $2s'$ and $2s''$ for second and third orders if possible, so they can calculate the λ from each maxima using their measured value of $2s$ divided by 2. In addition, they could calculate the mean λ from all the maxima they can observe. This will increase the accuracy of the calculated value of λ . It also shows the importance to be able to observe as many maxima as possible.
- ▶ The distance between maxima (s) will increase as the screen is placed further from the grating (which will also increase D). This will increase the precision of the calculated λ , because the uncertainties over measurements of lengths will be spread over longer distances. However, the maxima get fainter and broader, so identifying centre becomes more difficult. The discussion around these issues is more important than obtaining a specific answer from the students.
- ▶ The uncertainty of the value of λ could be estimated as the range of λ s divided by 2:

$$\text{Uncertainty}(\lambda) = \frac{(\lambda_{\text{max}} - \lambda_{\text{min}})}{2}$$

The value of the laser pointer's wavelength is likely to be printed on the device's label, so this part of the investigation could be used as a confirmation that the method used is valid and accurate enough to obtain precise and accurate data. In fact, the students could check whether the wavelength printed on the laser pointer is within the range of λ they calculated. In other words, is the λ of the device (as stated by the manufacturer) within $\lambda \pm \text{Uncertainty}(\lambda)$? If so, the students have reasonably good results.

- ▶ They could use graph paper stuck to the screen to increase the precision of their measurements of s .