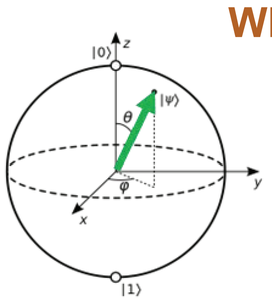
MECHANICAL ANALOGUE OF QUBITS

1. Project Introduction

Objective: Construct a **mechanical analog** of a Qubit using a magnetised gyroscope and demonstrate the ability to **manipulate its orientation** through **applied magnetic fields**

What is a Qubit?



Bloch representation
Qubit state

Qubits are **basic units of quantum information** found in the form of a **two-state** quantum-mechanical system

Density Matrix: $\hat{\rho} = |\psi\rangle\langle\psi|$ describes qubit state

Density matrix then evolves to:

$$\frac{d\hat{\rho}}{dt} = \frac{1}{i\hbar}[\hat{H}, \hat{\rho}]$$

$\hat{H} = \boldsymbol{H}.\boldsymbol{\sigma}$ is the Hamiltonian: the total energy of the system.

Bloch Equation:

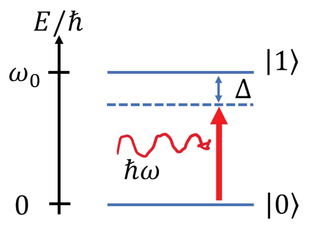
$$\frac{d\boldsymbol{\rho}}{dt} = \frac{1}{i\hbar}\boldsymbol{H} \times \boldsymbol{\rho} = \boldsymbol{\Omega_e} \times \boldsymbol{\rho}$$

$\boldsymbol{H} = \hbar\boldsymbol{\Omega_e}$ is the rotation rate

2. Equivalence of Qubits and Magnetic Gyroscope

2-State energy levels of a Qubit

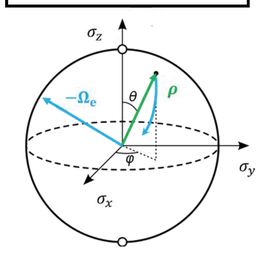
Ω: Rabi frequency
Δ: Detuning from the resonance frequency ω_0



Application of EMF can manipulate states, allowing the quantum states to superpose

Bloch Equation of Qubit

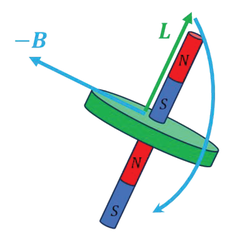
$$\frac{d\boldsymbol{\rho}}{dt} = \boldsymbol{\Omega_e} \times \boldsymbol{\rho}$$



The Hamiltonian vector $\boldsymbol{H}$ rotates the Bloch vector $\boldsymbol{\rho}$, about at a rate $|\boldsymbol{\Omega_e}|$ about the Bloch sphere

Magnetic Gyroscope precessing about magnetic field

$$\frac{d\boldsymbol{L}}{dt} = \frac{M}{L}\boldsymbol{B} \times \boldsymbol{L}$$

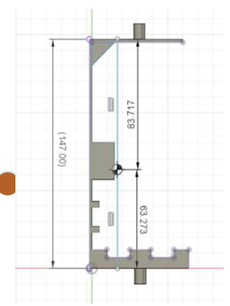


B is the Magnetic field applied
L is the Angular momentum of Gyroscope
M is the magnetic dipole moment

3. Methodology

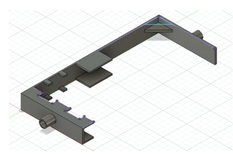
Coiled **Copper solenoids** to generate a uniform magnetic field

Solid brass with a lightweight aluminium frame (148.4g)



Center of gravity of the gyroscope holder found using Fusion 360

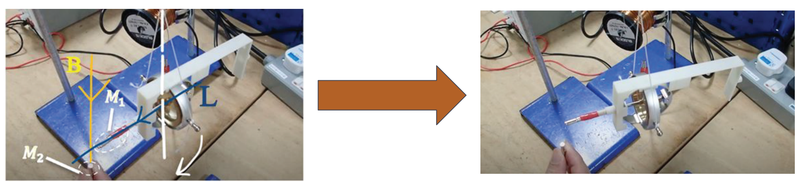
$Mass_{CW}$ = 1.40 g.



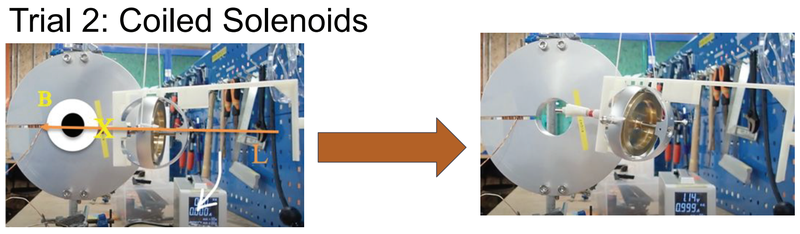
Fusion 360 used to design before being 3D printed out of **PLA+ filament.**

4. Results and Discussion

Trial 1: Permanent magnets



Trial 2: Coiled Solenoids



5. Conclusion

- ❏ The **greater** the magnetic field strength the **larger the rate** of gyroscopic precession
- ❏ Qubits can be mapped using a **magnetised gyroscope**
- ❏ A magnetised gyroscope can be used to understand **fundamental concepts** of quantum mechanics at an **introductory** level

6. Future Work

- ❏ Use of **Mu Metal Shields** to shield the gyroscope from the magnetic field
- ❏ Replacing strings with a **holder** has less friction
- ❏ Explore the effects of **reducing friction** between the spin axes on the change in angular momentum

Acknowledgement and References

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[1]Fano, U. (1957). "Description of States in Quantum Mechanics by Density Matrix and Operator Techniques". *Reviews of Modern Physics*

[2]The Pauli spin matrices - The Feynman Lectures on Physics

[3]Poincare Sphere with Polarizations.svg - Wikimedia Commons. (2010, October 1)

[4]Torrey, H C (1956). "Bloch Equations with Diffusion Terms". Physical Review. 104 (3): 563–565.

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YDSP Young Defence Scientists Programme
DSTA Defence Science & Technology Agency
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