Theoretical Question 3: “Quantum effects of gravity”
Th.G. 3: “Quantum effects of gravity”. Classical description
Classically, the cavity behaves as a vertical velocity selector.
Classically, the cavity behaves as a vertical velocity selector.

1. Balls with high $v_z$ will eventually hit the absorber:

$$|v_z(z)| < v_{\text{max}}(z)$$  (energy conservation)

Th. G. 3: “Quantum effects of gravity”. Classical description
Classically, the cavity behaves as a vertical velocity selector.

1. Balls with high $v_z$ will eventually hit the absorber:
$$|v_z(z)| < v_{\text{max}}(z)$$ (energy conservation)

2. One up-down cycle is necessary in order to select velocities $\rightarrow$ minimum time and length $t_c, L_c$

*Th.9. 3: “Quantum effects of gravity”.  Classical description*
Classically, the cavity behaves as a vertical velocity selector.

1. Balls with high $v_z$ will eventually hit the absorber:
   $$|v_z(z)| < v_{\text{max}}(z)$$  
   (energy conservation)

2. One up-down cycle is necessary in order to select velocities $\rightarrow$ minimum time and length $t_c, L_c$

3. Number of balls at D:
   $$N_c \propto \int_0^H dz \, 2v_{\text{max}}(z)$$

*Th. 3: “Quantum effects of gravity". Classical description*
Classically, the cavity behaves as a vertical velocity selector.

1. Balls with high $v_z$ will eventually hit the absorber: $|v_z(z)| < v_{\text{max}}(z)$ (energy conservation)

2. One up-down cycle is necessary in order to select velocities $\rightarrow$ minimum time and length $t_c, L_c$

3. Number of balls at D: $N_c \propto \int_0^H dz \, 2v_{\text{max}}(z)$

**Th.G. 3: “Quantum effects of gravity”.** Classical description
For neutrons \((mv_zH \sim h)\), the cavity behaves as an energy selector.

1. Balls with high \(v_z\) will eventually hit the absorber: 
   \[ |v_z(z)| < v_{\text{max}}(z) \]  
   (energy conservation)

2. One up-down cycle is necessary in order to select velocities \(\rightarrow\) minimum time and length \(t_c, L_c\)

3. Number of balls at \(D\): 
   \[ N_c \propto \int_0^H dz \ 2v_{\text{max}}(z) \]

*Th. 3: “Quantum effects of gravity”. Quantum description*
For neutrons \((mvzH \sim h)\), the cavity behaves as an energy selector

1. Energy levels
   \[ E_n = E_1 n^{2/3} \]
   (BS quantization rule — \textsc{Provided})

2. One up-down cycle is necessary in order to select velocities
   \[ \rightarrow \text{ minimum time and length } t_c, L_c \]

3. Number of balls at \(D\):
   \[ N_c \propto \int_0^H dz \ 2v_{\text{max}}(z) \]

\textit{Th. \textsc{Q.} 3: “Quantum effects of gravity”. Quantum description}
For neutrons \((mv_zH \sim h)\), the cavity behaves as an energy selector

1. Energy levels \(E_n = E_1 n^{2/3}\) (BS quantization rule — PROVIDED)

2. Time necessary to observe the first quantum level (Uncertainty relations: \(\Delta t \gtrsim h/\Delta E \gtrsim h/E_1\))

3. Number of balls at \(D\): \(N_c \propto \int_0^H dz \, 2v_{\text{max}}(z)\)

**Th.9.3: “Quantum effects of gravity”**. Quantum description
For neutrons \((mv_zH \sim h)\), the cavity behaves as an energy selector

1. Energy levels \(E_n = E_1 n^{2/3}\)
   
   (BS quantization rule — PROVIDED)

2. Time necessary to observe the first quantum level
   
   (Uncertainty relations: \(\Delta t \gtrsim h/\Delta E \gtrsim h/E_1\))

3. Number of neutrons at \(D\):
   
   \(N_q = \int_0^H dz \, I(z)\)
   
   (intensity proportional to (amplitude)²)

**Th.G. 3: “Quantum effects of gravity”. Quantum description**
Sketch of experimental data for neutron counting:

Only the first quantum sharp increase is analysed

Th.G. 3: "Quantum effects of gravity".
Sketch of experimental data for neutron counting:

Only the first quantum sharp increase is analysed

Th.G. 3: “Quantum effects of gravity”.
Sketch of experimental data for neutron counting:

Only the first quantum sharp increase is analysed

Th. 9. 3: “Quantum effects of gravity”.
**Objective:**

Compare classical and quantum predictions for neutrons in the Earth’s gravitational field.

**Main references:**

V. V. Nesvizhevsky et al.,

“(Measurement of) quantum states of neutrons in the Earth’s gravitational field”,

Precedent:

“Electron interference”

- 5th Iberoamerican Physics Olympiad, Jaca 2000, Spain
- 24th International Physics Olympiad, Williamsburgh 1993, U.S.A.

Th.9. 3: “Quantum effects of gravity”. 
Concepts involved:

- Energy conservation
- Heisenberg’s uncertainty relations
- Energy levels of quantum systems
- Waves: intensity proportional to (amplitude)^2

Th.9. 3: “Quantum effects of gravity”. 
36th International Physics Olympiad
Salamanca, Spain
3–12 July 2005

Theoretical Question 3:
“Quantum effects of gravity”