

# Neutrino—Induced Torque on Macroscopic Object

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## Abstract

We discuss the possibility of table-top experiments to demonstrate the neutrino-induced torque on macroscopic matter. The proposed setup employs a small, ferromagnetic, e.g., ring-shaped, samples magnetically levitated above the superconductor and containing nuclei that undergo electron capture (EC) decay. At deep cryogenic temperatures, nuclear spin polarization of the EC-decaying nuclei enables controllably directional neutrino emission, giving rise to a detectable mechanical torque on the sample. We estimate the expected magnitude of the effect and discuss the key experimental requirements and challenges, including the choice of suitable EC isotopes, achievable polarization degrees, and sensitivity limitations. If realized, such an experiment would provide a rare direct demonstration of neutrino-matter angular momentum transfer at macroscopic scale.<sup>1</sup>

## 1 Introduction

Neutrinos are almost massless particles participating in the weak and gravitational interactions. Having zero charge, minuscule masses and tiny cross-sections, neutrinos usually penetrate ordinary matter with negligible consequences. Yet, when the interaction of neutrinos with matter particles indeed occurs, they exchange the momentum and energy at full strength. Consequences of such four-momentum ( $E, p$ ) exchange of neutrinos are well known: *A) missing energy*: was observed in the radioactive heat balance of the beta-decaying sample of  $^{210}\text{Bi}$  [1] in 1927 (see Fig. 1a). Neutrinos take away  $\sim 2.3\%$  of the Sun total energy output, antineutrinos take away 69% of energy released in  $^3\text{H} \rightarrow ^3\text{He} + e^- + \bar{\nu}_e$  beta decay and 99% of the energy released in the violent core-collapse supernova events is released in the form of neutrinos. *B) missing momentum*: carried away by the neutrinos is clearly visible e.g. in the beta-decay of muons (observed in LAr [2] or gaseous TPC) and it was identified also in early 1956 experiments [3] with  $^6\text{He} \rightarrow ^6\text{Li} + e^- + \bar{\nu}_e$  decay studied in the expansion type of Wilson chamber.

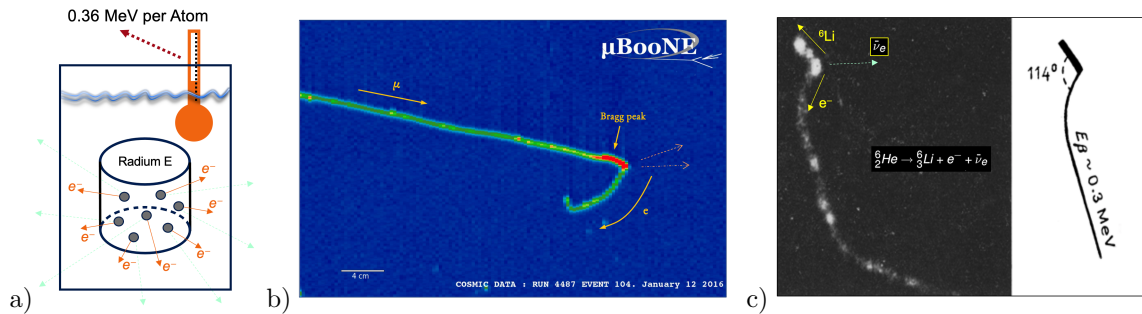


Figure 1: a) Missing energy in the calorimetry measurement [1]; b) missing momentum of neutrino(s) implied in LAr TPC [2], c) photo from the Wilson chamber [3] observing  $^6\text{He} \rightarrow ^6\text{Li} + e^- + \bar{\nu}_e$  decay.

Postulated by W. Pauli in 1930 to explain continuous energy spectrum of the emitted electrons in  $\beta$  decay experiments, neutrinos (and anti-neutrinos) carry also angular momentum of the same size as do protons, electrons or muons. This angular momentum (internal spin) of neutrinos was measured to be antiparallel to the velocity of emitted neutrinos in the pioneering BNL table-top experiment [4] using sample of  $^{152m}\text{Eu}$  nuclei decaying by K-electron (EC) capture into  $^{152}\text{Sm}^*(J=1)$  excited state.

<sup>1</sup>This is an enhanced version of Neutrino'26 poster, presented during *Session I* at UCI, 23.6.2026, Irvine, CA.

Quantitatively, helicity of tau ( $\tau$ )-neutrinos is measured as:  $h_\nu(\tau) = -0.93 \pm 0.14$  [5], for  $\mu$ -neutrinos  $h_\nu(\mu) = -1.06 \pm 0.11$  [6], and for electron-type neutrinos emitted in  $\beta$  decay the helicity value obtained recently from  $^{56}\text{Co} + e^- \rightarrow ^{56}\text{Fe}^* + \nu_e$  EC decay is:  $h_\nu(e) = -1.02$  with 20% uncertainty [7].

The purpose of this Neutrino'26 poster [8] is to discuss the possibility of a direct measurement of the neutrino-induced angular momentum transfer to the macroscopic matter. Although the macroscopic measurement [1] of the calorimetric missing energy due to escaping neutrinos exists, there is (to our best knowledge) no experimental demonstration of the neutrino flux momentum exchange with the *macroscopic* matter, or a measurement of the total angular momentum transfer of the neutrino flux to the macroscopic matter sample.

## 2 Neutrino-induced angular thrust (due to recoil force)

The idea to measure neutrino-induced recoil force acting on beta-decaying macroscopic sample has been recently evaluated in [9] and several EC-decaying isotopes have been considered. Among them, decay  $^{163}\text{Er} + e^- \rightarrow ^{163}\text{Ho} + \nu_e$  is estimated to generate macroscopic recoil force (thrust)  $F \approx m \cdot 8 \cdot 10^{-9}$  N/g for the sample of  $^{163}\text{Er}$  nuclei with activity starting at  $\alpha_m = 710$  kBq. Also  $^{55}\text{Fe}$  decay with  $E_\nu = 225$  keV is considered [9], with minimal sample mass  $m = 8.6$  ng of activity 760 kBq, assuming *unmeasured* magnetic moment  $\mu = +2.7\mu_N$  of  $^{55}\text{Fe}_{3/2}$  nucleus (Appendix B shows  $^{55}\text{Fe}$  and  $^{163}\text{Er}$  decay scheme).

Here, we shall consider the angular thrust, created in the macroscopic ring of ferromagnetic or ferrimagnetic material (with toroidal magnetization), containing EC decaying nuclei which are capable of the directional emission of neutrinos when polarized by the remanent magnetic field at cryogenic temperatures (see Fig. 2). To be more explicit, we consider  $\text{ErFe}_2$  or  $\text{HoFe}_2$  ferrimagnetic materials having cubic Laves phase structure [10].

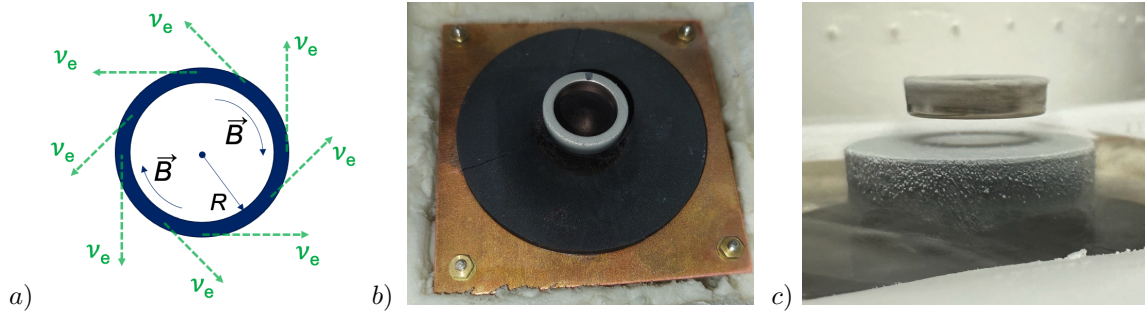


Figure 2: a) Momenta of neutrinos escaping from toroidally magnetized ring; b),c) photos of NdFeB magnetic rings above YBCO superconductor, during the levitation persistence tests in our laboratory.

The above figure shows *schematically* the oriented neutrino flux emitted from the polarized sample of nuclei, decaying by Gamow-Teller EC transition, exhibiting directional asymmetry of the neutrino emission. It is obvious that recoil force generated by such directional flux of neutrinos exhibits net angular torque on the cryo-cooled macroscopic ring containing the polarized EC-decaying nuclei.

Table 1: Parameters of Er and Fe decaying isotopes taken from [9] which we consider here for the angular momentum thrust experiments with the suspended magnetized samples.

| EC decay                                                | $T_{1/2}$ [h] | $\mu$ [ $\mu_N$ ] | $E_\nu$ [keV] | $f_0$ [N/g]           | $M_{\min}$ [g]        | $\alpha_{\min}$ [MBq] | $W_{\min}$ [nW] |
|---------------------------------------------------------|---------------|-------------------|---------------|-----------------------|-----------------------|-----------------------|-----------------|
| $^{163}\text{Er}(5/2) \rightarrow ^{163}\text{Ho}(7/2)$ | 1,25          | 0,56              | 1164          | $8 \times 10^{-9}$    | $1,3 \times 10^{-12}$ | 0,7                   | 5,4             |
| $^{165}\text{Er}(5/2) \rightarrow ^{165}\text{Ho}(7/2)$ | 10,4          | 0,64              | 332           | $3 \times 10^{-10}$   | $3,2 \times 10^{-11}$ | 2,2                   | 16              |
| $^{55}\text{Fe}(3/2) \rightarrow ^{55}\text{Mn}(5/2)$   | 24000         | 2,??              | 225           | $1,2 \times 10^{-12}$ | $8,6 \times 10^{-9}$  | 0,8                   | 0,7             |

Reasons for considering the exotic  $\text{ErFe}_2$  and  $\text{HoFe}_2$  ferrimagnetic materials are: *A)* internal hyperfine magnetic fields of the magnetized samples are 600-800 Tesla at Er or Ho nuclei and still pretty large at Fe nucleus site (21 Tesla), *B)* these materials keep their remanent magnetization at room temperatures and thus toroidal magnetization can be created quite conveniently, *C)*  $^{163}\text{Er}$  and  $^{55}\text{Fe}$  decay via EC process with directionally emitted neutrinos [9]. Additionally,  $^{163}\text{Ho}$  isotope (see Appendix B) with magnetic moment  $4.2\mu_N$ , may also be used. In Appendix A, we show the polarization estimates.

Assuming  $^{165}\text{Er}$  sample with activity 2.2 MBq, the linear acceleration  $\mathbf{a}$  of the sample with the mass  $2 \times M_{\min} = 6.4 \cdot 10^{-11} \text{ g}$  (we consider e.g.  $\text{ErFe}_2$  sample with admixture of stable Er isotopes) would be according to Eq.(26) in [9] (using  $C_n = 1$ ):

$$F_{0z}/2M_{\min} = \mathbf{a} = -(B/T)f_0/2 = -1.5(B/T) \times 10^{-10} \text{ ms}^{-2} \quad (1)$$

This would generate angular acceleration:  $d\omega/dt = -(B/T)f_0/2R$ , assuming the moment of inertia  $I = 2M_{\min}R^2$  for the magnetized ring, and angular thrust  $T_a = F_{0z} \times R$ . For  $R = 0.002 \text{ m}$  one has  $d\omega/dt = 7.5 \times 10^{-8} \text{ rad/s}^2$ , which gives one full turn in less than 4 hours, if (air) friction is neglected. We believe such small angular acceleration can be measured (see considerations in [Appendix E](#)).

### 3 Neutrino-induced spin transfer

We consider a rod of  $\text{ErFe}_2$  ferrimagnet polarized longitudinally and cooled to cryogenic temperature, so that e.g. 35% of  $^{163}\text{Er}$  nuclei are polarized. The cooled sample is emitting neutrinos preferentially in one direction and it is suspended by the superconducting cylinder or attached to torsion pendulum (see Fig. 3). For every captured electron (we assume 1s, 2s, EC electrons are not polarized in  $\text{ErFe}_2$  magnet) a neutrino is leaving the sample with negative helicity  $\Rightarrow$  taking away angular momentum  $\Delta J_z = \hbar/2$ . Momentum conservation requires angular momentum of the escaping neutrinos to be accrued in  $\text{ErFe}_2$  sample (e.g. polarized  $^{163}\text{Er}_{5/2}$  EC decay generates polarized  $^{163}\text{Ho}_{7/2}$ ) and eventually angular momentum, being increasingly accumulated in  $\text{Er}_{1-x}\text{Ho}_x\text{Fe}_2$  ferrimagnet sample, may be transferred to the lattice via hyperfine spin-orbit coupling. If such spin-lattice transfer process indeed happens (see more detailed discussion in the [Appendix C](#)), the magnetized rod can exhibit torque (may start rotating) around its long-symmetry axis.

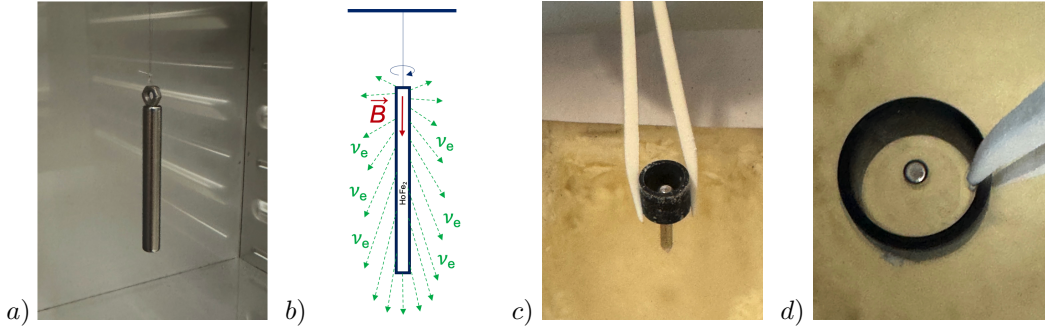


Figure 3: a) Magnetized NdFeB rod suspended on torsion balance in thermal chamber in our Lab.; b)  $\nu_e$  neutrino flux from  $\text{Er}(\text{Ho})\text{Fe}_2$  considered; c) and d) a magnetic rod suspended by YBCO ring.

As the extreme case, let us consider activity 1 MCi which means  $3.7 \times 10^{16}$  neutrinos leave the sample every second. After 10 hours, the escaped angular momentum is  $7 \times 10^{-14} \text{ J.s}$ , which can be compensated, for example, by a measurable rotation of a suitably suspended  $\text{Er}_{1-x}\text{Ho}_x\text{Fe}_2$  rod. Assuming mass of the 1 MCi radioactive  $\text{ErFe}_2$  rod (1 mm thick, 6.5 cm long) to be 0.5 g, one has  $\omega \approx 1 \cdot 10^{-3} \text{ rad/s}$ , if  $7 \times 10^{-14} \text{ J.s}$  angular momentum is transferred to the lattice. Such rotation (if caused by a constant torque during 10 hours) gives angular acceleration  $d\omega/dt \approx 3 \cdot 10^{-8} \text{ rad/s}^2$ , a full rotation in less than 6 hours, and torque  $T \approx 2 \cdot 10^{-18} \text{ N.m}$ , which is measurable by modern torsion balances. Degree of polarization ([Appendix A](#)) is not included in the above rough estimates, and 1 MCi activity of  $^{163}\text{Er}$  generates  $\sim 70 \text{ mW}$  of heat, which makes the cryogenic cooling non-trivial.

### 4 Summary and Conclusion

We have considered two setups potentially allowing for the measurement of angular momentum transfer to the macroscopic matter due to directional neutrino flux generated by polarized EC-decaying nuclei. Although experimental requirements are tough, we think the goal is worth of consideration. Additionally, using radioactive  $^{55}\text{Fe}$  in the cryo-cooled magnetized  $\text{Er}/\text{HoFe}_2$  (or  $\alpha$ -iron) samples may allow one to measure the magnetic moment of  $^{55}\text{Fe}$  nucleus (see [Appendix D](#)).

## Acknowledgements

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## Appendix A: Nuclear Polarization

Degree of polarization of  $^{163}\text{Er}$ ,  $^{163}\text{Ho}$  and  $^{163}\text{Dy}$  nuclei can be evaluated using Eq.(23) from paper [9]. A nucleus with spin  $J$  and magnetic moment  $\mu$ , exposed to the magnetic field  $B$ , achieves the equilibrium polarization at given temperature  $T$ :

$$P = \frac{2J+1}{2J} \coth\left(\frac{\beta(2J+1)}{2J}\right) - \frac{1}{2J} \coth\left(\frac{\beta}{2J}\right) \quad (2)$$

with factor  $\beta = \mu B / (k_B T)$ . Assuming 700 Tesla hyperfine magnetic field in ferrimagnetic  $^{163}\text{Ho}/\text{ErFe}_2$  samples, one obtains surprisingly large ( $\sim 40\%$ ) polarization for  $^{163}\text{Ho}$  nuclei at moderate temperatures (e.g 1 K), which can be reached by the evaporative cooling in  $\text{He}^4$  refrigerators. On contrary, the polarization of  $^{163}\text{Er}$  nuclei to  $P \approx 40\%$  level requires  $\sim 200$  mK temperatures, due to much smaller magnetic moment  $\mu = 0.557 \mu_N$ . Thus, large magnetic moment  $\mu = 4.23 \mu_N$  of  $^{163}\text{Ho}$  nucleus makes this isotope favorable for the experiments we are discussing (stable  $^{165}\text{Ho}$  isotope has  $\mu = 4.17 \mu_N$ ).

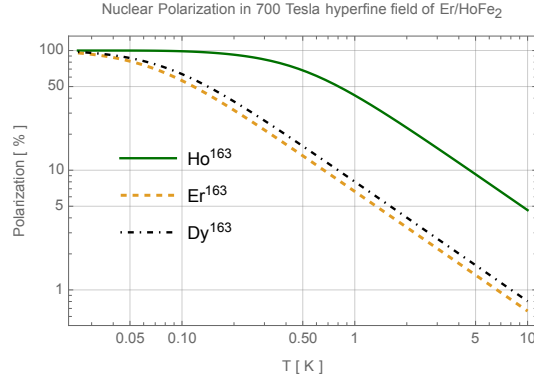


Figure 4: Polarization of selected nuclei in 700 Tesla hyperfine field of  $^{163}\text{Er}/\text{Dy}/\text{HoFe}_2$  ferrimagnet.

Since the magnetic moment of  $^{55}\text{Fe}$  ground state ( $J = 3/2$ )<sup>-</sup> is unknown, we may assume *some* magnetic moment value for the polarization calculation. In Fig. 5, we show the predicted polarization of  $^{55}\text{Fe}$  nuclei in the magnetized sample of  $\text{HoFe}_2$ . Due to smaller hyperfine fields  $\approx 21$  T in  $\text{HoFe}_2$  lattice at Fe-sites,  $\sim 5 - 50$  mK temperatures are needed for the  $^{55}\text{Fe}$  polarization and the magnetic moment determination. Such temperatures were readily achievable with NICOLE<sup>2</sup> dilution  $^3\text{He} - ^4\text{He}$  refrigerator [11] at ISOLDE/CERN .

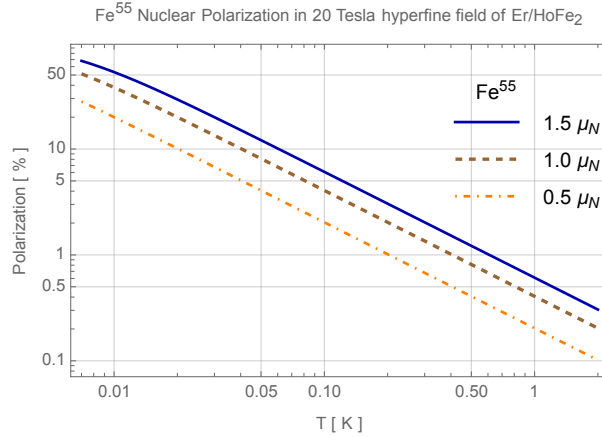


Figure 5: Polarization of  $^{55}\text{Fe}$  nucleus in hyperfine field 20 Tesla of  $^{163}\text{Er}/\text{HoFe}_2$  ferrimagnet.

<sup>2</sup>Note: NICOLE The refrigerator has been disassembled and is currently unavailable.

## Appendix B: EC-decays of $^{163}\text{Er}$ , $^{163}\text{Ho}$ and $^{55}\text{Fe}$

Here we show decay schemes of the considered isotopes decaying via electron capture (EC) process:

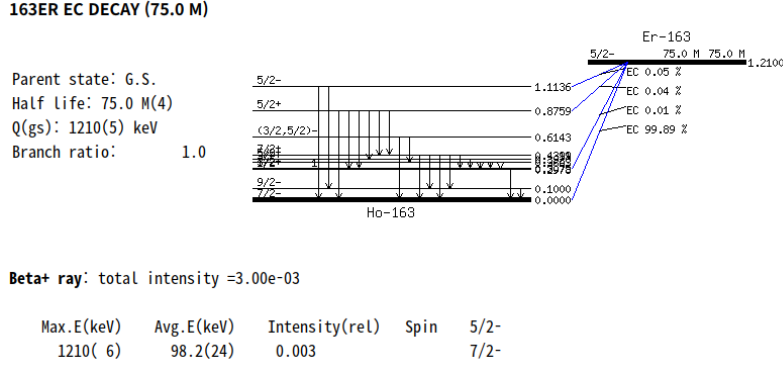


Figure 6: Decay of  $^{163}\text{Er}$  from <https://atom.kaeri.re.kr/cgi-bin/decay?Er-163%20EC>

In Fig. 7, we show  $^{163}\text{Ho}$  nucleus decay scheme with half-life 4570 years and decay energy  $Q = 2.5$  keV.

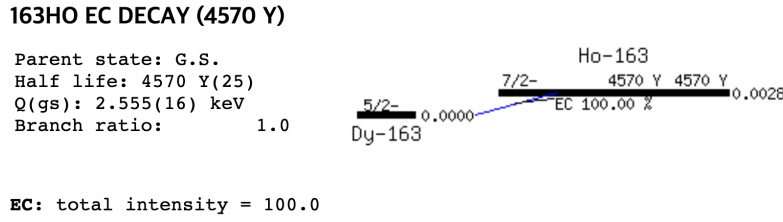


Figure 7: Decay scheme for  $^{163}\text{Ho}$  from <https://atom.kaeri.re.kr/cgi-bin/decay?Ho-163%20EC>

In Fig. 8, we show decay scheme for  $^{55}\text{Fe}$ . Low probability of 126 keV gamma emission ( $1.28 \times 10^{-9}$ ) is indicated. The probability of IB gamma emission is approx is 23400 times higher:  $3 \times 10^{-5}$  [16].

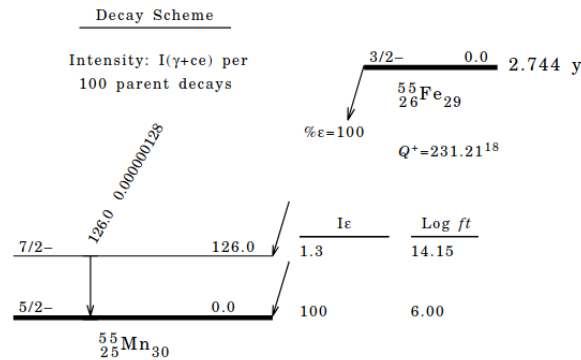


Figure 8: Decay scheme for  $^{55}\text{Fe}$  from NDS [20] for  $A = 55$ .

## Appendix C: Spin-balance in Er/HoFe<sub>2</sub> magnetized rod

Here we elaborate on the mechanism of the missing angular momentum transfer (the spin taken away by neutrinos) from the sample of polarized EC-decaying nuclei to the macroscopic magnetized sample (lattice). In principle, we assume nuclear-spin to electron-spin transfer caused by the hyperfine interaction, and subsequent spin-orbit transfer of angular momentum for electrons. The first mechanism allows the polarization of daughter nuclei to be transferred to electrons, while the second mechanism transfers the electron spin angular momentum to the electron orbital angular momentum, which may then be taken by the lattice (third mechanism) resulting in the macroscopic angular momentum.

Besides  $^{163}\text{ErFe}_2$  sample decaying to  $^{163}\text{ErHo}_x\text{Fe}_2$  (lifetime of  $^{163}\text{Er}$  is 75 minutes - see [Appendix B](#)) we shall also consider  $^{163}\text{HoFe}_2$  sample decaying to  $^{163}\text{HoDy}_x\text{Fe}_2$  (lifetime of  $^{163}\text{Ho}$  is 4570 years). Although the energy of neutrinos from EC-decaying  $^{163}\text{Ho}$  nuclei is very low (below 2 keV), the angular momentum (spin) taken away by each neutrino is the same as in the case of 1164 keV neutrinos [\[9\]](#) from  $^{163}\text{Er}$  decays. Thus, the radioactivity heat due to the recoils is minimal in the case of  $^{163}\text{Ho}$  decays, while the missing momentum effect is of the same size as in  $^{163}\text{Er}$  decays: roughly  $\hbar/2$ , for every emitted neutrino.

Both decays,  $^{163}\text{Ho} + e^- \rightarrow ^{163}\text{Dy} + \nu_e$  and  $^{163}\text{Er} + e^- \rightarrow ^{163}\text{Ho} + \nu_e$ , proceed by the allowed Gamow-Teller transitions, with directional neutrino emission if the parent nucleus is polarized. There is a significant difference in the magnetic moments of these nuclei, however:  $\mu = 0.557\mu_N$  for  $^{163}\text{Er}$ , and  $\mu = 4.23\mu_N$  for  $^{163}\text{Ho}$ , while  $\mu = 0.673\mu_N$  for  $^{163}\text{Dy}$ .

Thus, if  $^{163}\text{Er}$  nuclei are polarized by the magnetic field and decay via capturing electrons, the resulting  $^{163}\text{Ho}$  nuclei will stay in the polarized state due their  $7.6\times$  stronger interaction with the magnetic field (see [Fig. 4](#)). Since the neutrinos (taking away  $\hbar/2$  of angular momentum) do not interact with the lattice of the magnetized specimen, it is only a disappearance of the  $\hbar/2$  spin of the captured  $1s, 2s$  electrons (polarized holes), which effectively interact (via the electrons filling the polarized vacancy) with the total angular momentum of the lattice (we name this mechanism as  $\Delta J_e$ ).

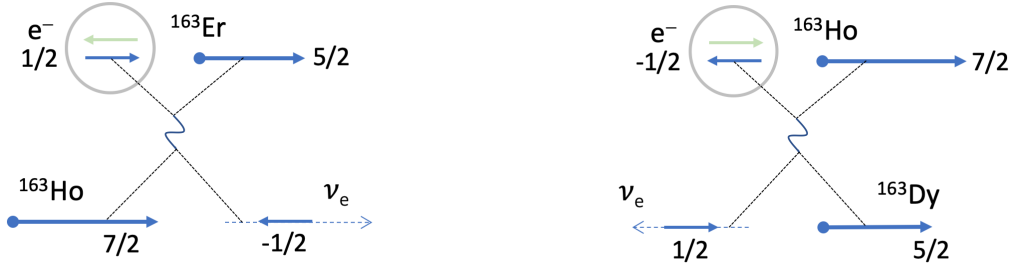


Figure 9: Here we show the angular momentum balance in polarized  $^{163}\text{Er}$  and  $^{163}\text{Ho}$  decays.

If  $^{163}\text{Ho}$  nuclei are polarized by the magnetic field and decay by capturing electrons, the resulting  $^{163}\text{Dy}$  polarized nuclei will tend to depolarize due their  $6.3\times$  weaker interaction with the polarizing hyperfine magnetic field (see [Fig. 4](#)). Thus, in case of  $^{163}\text{HoFe}_2$  sample, the hyperfine interaction may additionally transfer the angular momentum from the polarized daughter  $^{163}\text{Dy}$  nuclei (after decay) to electrons and then to the lattice of the cryogenic sample (we name this mechanism as  $\Delta J_n$ ).

Note, that angular momentum transfer mechanism  $\Delta J_n$  for the polarized  $^{163}\text{Ho}$  nuclei is present simultaneously with the mechanism  $\Delta J_e$ , just in  $^{163}\text{Ho}$  case, the capture of electrons proceeds mainly from  $M, N$  electronic orbitals (electrons from  $K, L$  energy levels cannot be captured due to the energy constraints). Each depolarization of  $^{163}\text{Dy}$  daughter nucleus may transfer  $\Delta J_n = 5\hbar/2$  of angular momentum to lattice, which is  $5\times$  more if compared to the polarized vacancy mechanism  $\Delta J_e = \hbar/2$ .

Thus, self-induced angular thrust of the ferromagnetic sample, generated by weak decays of the polarized nuclei, originates from two possible sources of the internal spin-lattice relaxation: from the spin-polarized electron-vacancies ( $\Delta J_e$ ) and from depolarization of the daughter nuclei ( $\Delta J_n$ ).

Of course, during depolarization of the magnetically-polarized ensemble of nuclei (e.g. if temperature of the cryo-cooled  $^{165}\text{HoFe}_2$  ferrimagnet rises from 0.5 K to 10 K, *nuclear* Einstein-de Haas effect should occur (due to hyperfine interaction) and exhibit itself via measurable torque on  $\text{HoFe}_2$  sample.

## Appendix D: Measuring the Magnetic moment of $^{55}\text{Fe}$

Surprisingly, magnetic moment of  $^{55}\text{Fe}$  nucleus ground state has not been measured yet. The nuclear data tables [12] indicate  $\mu = 2.7\mu_N$  for  $(J = 5/2)^-$  excited 931 keV state  $^{55}\text{Fe}^*$  without any value given for the  $(J = 3/2)^-$  ground state. Very small branching ratio ( $1.3 \times 10^{-9}$ ) of EC decay (see Fig. 8), to the first excited (126 keV) state of  $^{55}\text{Mn}^*$ , does not allow for utilizing 126 keV gamma radiation for the magnetic moment of  $^{55}\text{Fe}$  to be determined (via daughter  $^{55}\text{Mn}^*$  polarization) from circular polarization of the emitted 126 keV gammas. Moreover, mean lifetime of 126 keV  $^{55}\text{Mn}^*$  excited state  $\tau = 382 \pm 16$  ps [13] is too long for attempting the spin-neutrino angular correlation method [14] in case of  $^{55}\text{Fe}$  decay ( $^{55}\text{Mn}^*$  recoil energy is small for measuring Doppler-shift of the 126 keV gammas).

However, internal EC bremsstrahlung (IBEC) is  $\sim 24000\times$  more probable than 126 keV gamma emission and the magnetic moment of  $^{55}\text{Fe}$  nucleus may likely be measured as in the  $^{37}\text{Ar}$  case [15]: using the angular asymmetry of IB radiation from the cryocooled (polarized)  $^{55}\text{Fe}$  sample. IB spectrum of  $^{55}\text{Fe}$  extends up to 232 keV [16] and ferromagnetic  $\alpha$ -iron lattice exhibits hyperfine fields  $B_{\text{hf}} \approx 33$  T. Magnetized sample of ferrimagnetic Ho/ErFe<sub>2</sub> also guarantees stable  $B_{\text{hf}} \approx 21$  T hyperfine fields at Fe nucleus sites, and thus ultra-low temperature variation is sufficient to obtain the polarization curve of  $^{55}\text{Fe}$  nuclei in the  $\alpha$ -iron or Er/HoFe<sub>2</sub> samples. Commercially,  $^{55}\text{Fe}$  sources are available with activities 1 mCi – 100 mCi (37 MBq – 3,7 GBq) as electro-deposited  $\alpha$ -iron (BCC) on Cu substrate covered with nickel layer or  $\sim 0.30$  mm beryllium window [17].

In the case of  $^{37}\text{Ar}$ , the polarized IB asymmetry measurement was done  $\sim 40$  years ago [15], at the ISOLDE experiment (CERN), using  $^3\text{He} - ^4\text{He}$  dilution refrigerator NICOLE. The IB  $\gamma$ -radiation activity was observed by three HPGe detectors positioned at  $0^\circ, 90^\circ, 180^\circ$  relative to the magnetic field orientation.  $^{37}\text{Ar}$  nuclei were implanted into Fe sample which was soldered onto the cold metallic part of the NICOLE refrigerator. The counting rate of IB radiation in HPGe detectors was  $\sim 40$  Hz [15].

Depending on the odd-neutron quantum state in  $^{55}\text{Fe}$  nucleus, the magnetic moment for  $^{55}\text{Fe}_{3/2}$  ground state can be predicted to vary from  $\mu = -1.91\mu_N$  for pure  $2p_{3/2}$  case to  $\mu = +0.35\mu_N$  for very strong mixing of  $2p_{3/2}$   $1f_{5/2}$  and  $2p_{1/2}$  configurations. Thus, from theoretical side, the magnetic moment of  $^{55}\text{Fe}$  ( $J = 3/2^-$ ) isotope is not determined, and its measurement is justifiable.

Cryogenic temperatures required for the polarization of  $^{55}\text{Fe}$  nuclei to change significantly in the hyperfine magnetic field can be deduced from Fig. 10 (below) and from Fig. 5 in Appendix A, depending on the expected magnetic moment. Higher sample activity makes data taking time shorter, while internal heating of the sample may become issue with  $\sim \text{GBq}$  sources. From Table I in ref.[9] one reads  $W_t = 0.71$  nW heating power of 0.76 MBq  $^{55}\text{Fe}$  sample, which gives  $\sim 3.5 \mu\text{W}$  for 100 mCi source.

$$W(\theta) = 1 + A \cdot \alpha_{1s} \cdot P(T) \cdot \cos(\theta) \quad (3)$$

The equation given above gives asymmetry of IB  $\gamma$ -radiation from the polarized sample of nuclei, with angle  $\theta$  between magnetic field direction and emitted  $\gamma$  ray momentum,  $P(T) = \langle I_z \rangle / I$  is temperature-dependent polarization [18], asymmetry coefficient  $A = -I/I + 1 = -3/5$  for  $^{55}\text{Fe}$  ( $3/5 \rightarrow 5/2$ ) decay, and  $\alpha_{1s}$  is  $\gamma$ -energy dependent coefficient [18]. For a precise magnetic moment determination, one may apply NMR technique on oriented nuclei, used e.g. for  $^{69}\text{As}$  magnetic moment measurement [19], but classical  $^{37}\text{Ar}$  technique [15] (without NMR-induced depolarization) may also be realistic.

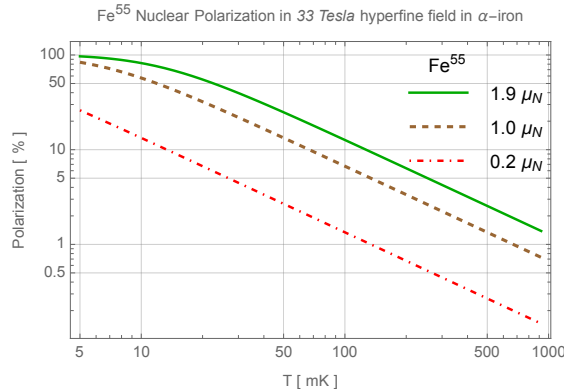


Figure 10: Polarization of  $^{55}\text{Fe}$  nuclei in 33 T hyperfine field of magnetic  $\alpha$ -iron.

## Appendix E: Torsion balance and Levitating setups

To estimate our capabilities in the sensitivity of the torsion balance setups, we have performed simple torsion pendulum experiments in our laboratory, as shown in Fig. 3a). Using the carbon steel wires (sold for LCD/OLED separation-cutting) of  $30\mu\text{m}$ ,  $50\mu\text{m}$ , and  $60\mu\text{m}$  diameter, torsion oscillations of the suspended NdFeB cylindrical magnets of known geometry and mass were measured. Torsion constant  $\mathcal{K}$  was determined from the period  $T$  of torsional oscillations using standard relations:

$$T = 2\pi\sqrt{\frac{I_m}{\mathcal{K}}} \quad \mathcal{K} = 4\pi^2 \frac{I_m}{T^2} \quad \left[ \mathcal{K}_0 \sim \frac{\pi G d^4}{32 L_0} \right] \quad (4)$$

where  $I_m$  is moment of inertia defined relative to vertical (symmetry) axis of the suspended object.

Table 2: Torsion constant measurements of the cutting wires tested in our laboratory.

| wire       | diameter         | period $T$ [s]  | length $L_0$ [m] | $I_m$ [kg.m <sup>2</sup> ] | $\mathcal{K}$ [N.m]·10 <sup>-7</sup> | $\mathcal{K} \cdot L_0$ |
|------------|------------------|-----------------|------------------|----------------------------|--------------------------------------|-------------------------|
| MRK006BG88 | 60 $\mu\text{m}$ | $5.9 \pm 0.2$   | $13.8 \pm 0.1$   | $3.186 \times 10^{-7}$     | $3.5 \pm 0.2$                        | $48 \times 10^{-7}$     |
| RL-059E    | 50 $\mu\text{m}$ | $1.87 \pm 0.03$ | $1.57 \pm 0.01$  | $3.186 \times 10^{-7}$     | $35.7 \pm 2.3$                       | $56 \times 10^{-7}$     |
| RL-059D    | 30 $\mu\text{m}$ | $4.76 \pm 0.16$ | $1.57 \pm 0.01$  | $3.186 \times 10^{-7}$     | $5.5 \pm 0.4$                        | $8.6 \times 10^{-7}$    |

We have obtained (see Table 2):  $\mathcal{K}_{30\mu} = (5.5 \pm 0.4) \cdot 10^{-7} \text{Nm/rad}$ , for  $30\mu\text{m}$  wire (RL-059D), and  $\mathcal{K}_{50\mu} = (3.6 \pm 0.2) \cdot 10^{-6} \text{Nm/rad}$ , for  $50\mu\text{m}$  wire (RL-059E), both wires were  $157 \pm 1 \text{cm}$  long. Additionally, we have measured torsion oscillations of  $L_o = (13.86 \pm 0.11)$  meters long  $60\mu\text{m}$  cutting wire (MRK006BG88), using the same suspended cylindrical NdFeB mass ( $I_m = 3.186 \cdot 10^{-7} \text{kg m}^2$ ), obtaining  $\mathcal{K}_{60\mu} = (3.54 \pm 0.23) \cdot 10^{-7} \text{Nm/rad}$  (active length  $L_o = 13.8 \text{m}$  of  $60\mu\text{m}$  wire was determined from it's pendulum oscillations period  $T = 7.47 \pm 0.03 \text{s}$ ).

Assuming  $d^4$  (circular wire diameter) scaling for torsion constant  $\mathcal{K}_0 \propto c \cdot d^4 / L_o$ , thickness of the wire allowing one to reach the required sensitivity  $\kappa' \sim 10^{-18} \text{Nm/rad}$  is  $d' = d_o(\kappa' / \mathcal{K})^{1/4} \sim 31 \text{nm}$  (using measured  $30\mu\text{m}$  wire constant  $\mathcal{K}_0 = 8.6 \times 10^{-7} \text{Nm/rad}$ ):

$$\frac{\kappa'}{\mathcal{K}_0} = \frac{1 \times 10^{-18}}{8.6 \times 10^{-7}} \approx \left( \frac{d'}{d_0} \right)^4 \quad d' = d_0 \sqrt[4]{\kappa' / \mathcal{K}_0} \sim 1.04 \times 10^{-3} \cdot d_0 \quad (5)$$

Such thin ( $d \approx 30 \text{nm}$ ) nano-wire can sustain the  $640 \text{ng}$  weight of ferrimagnetic  $^{163}\text{ErFe}_2$  ring mentioned in Section 2, but cannot bear the  $0.5 \text{g}$  weight of the magnetized  $\text{HoFe}_2$  rod considered in Section 3. (Note:  $30 \text{nm}$  thick carbon steel wire is capable to keep up the weight  $m_0 \sim 10^{-4} \text{gram}$ .)

Therefore, our attention turned to the magnetic levitation of the ferromagnetic (or ferrimagnetic) samples and the suspension of the magnetized samples (rods or rings) above or within (hollow) YBCO superconductors was successfully tested in our laboratory (see photos shown in Figure 2, and 3).

The magnetic ring, shown in Fig. 2b and 2c, is NeFeB magnet of radius  $5 \text{mm}$ , with dipole up-down magnetic polarization. In the realistic considered experiment, the mass of the ring containing  $\beta$ -decaying nuclei would be much smaller. In Section 2, we consider the ring of mass  $m \sim 6 \cdot 10^{-11} \text{g}$  and radius  $R \sim 2 \text{mm}$ , see Eq.(1). Moreover, toroidal magnetization of the  $\text{ErFe}_2$  rings, discussed in Section 2, is not favorable for the magnetic suspension above the superconductor, since toroidal magnetic fields do not spread out of the ring volume to interact at distance with the superconductor. Therefore, we find torsion nano-wire suspension to be suitable for suspending the cryo-cooled magnetized  $^{163}\text{ErFe}_2$  ring, emitting directional neutrino flux when EC-decaying nuclei are polarized.

For the magnetized  $\text{HoFe}_2$  rod (see Fig. 3), of the considered mass  $0.5 \text{g}$ , the magnetic suspension in a hollow YBCO superconducting cylinder seems to be realistic. We have successfully achieved the levitating suspension of the NeFeB magnetic rod inside commercially available hollow YBCO superconducting cylindrer at  $\text{LN}_2$  temperatures. Long-time stability of such levitating setup and systematic effects originating from temperature-dependent magnetic interaction (spontaneous rotation) of cylindrical magnets levitating above the superconductors [21] need to be understood.

Experimental demonstration of a small rotation, due to torque generated internally (via hyperfine-interaction), during depolarization of (stable)  $^{165}\text{Ho}$  nuclei in the magnetized  $^{165}\text{HoFe}_2$  rod, when temperature increases (e.g. from  $0.5 \text{K} \rightarrow 10 \text{K}$ , see Fig. 4), would become a demonstration of the *nuclear-induced* Einstein-de Haas effect. (Note: the spin of  $^{165}\text{Ho}_{7/2}$  nucleus, with  $\mu = 4.177 \mu_N$ , is seven times larger than the electron spin).