The Recoil Was Not Removed; the Crystal Took It Instead

— for the iron-57 line the recoil taken by a single atom is 4.198282×10^{5} times the natural linewidth, but taken by a 1 mg crystal it falls to 3.969200×10^{-14} of it — the separator is whether the recoil is taken by an atom or by a crystal — [Paper 664]

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— *From thinking to syncing.* —

Abstract

A gamma ray emitted by one nucleus is absorbed by another of the same kind. This looks straightforward and ordinarily cannot be done, because of recoil.What happens when the mass that takes the recoil is changed from an atom to a crystal is followed in numbers.No new theorem or law is claimed. First, with free atoms the lines do not overlap——for the 14412.9 eV line of iron-57, a single atom takes a recoil of 1.958440×10^{-3} eV against a natural linewidth of 4.664861×10^{-9} eV, a ratio of 4.198282×10^{5} (Section 2). **Second, this line is extremely narrow——the resolution, the linewidth divided by the energy, is 3.236588×10^{-13}, and shifting the line by one linewidth takes a speed of only 0.097030 mm/s** (Section 2). **Third, and this is the core. The recoil cannot be removed, but the receiver can be changed——when a 1 mg crystal (1.057715×10^{19} atoms) takes it, the recoil is 1.851577×10^{-22} eV, or 3.969200×10^{-14} of the linewidth** (Section 3). **Fourth, what it fell by is exactly the ratio of masses——the recoil of the atom over that of the crystal is 1.057715×10^{19}, agreeing to 10 digits with 1 mg divided by the mass of one atom, because the only thing in the formula is the mass that takes the recoil** (Section 3). **Fifth, thermal motion acts in the same way——in a gas of free atoms at 300 K the Doppler broadening is 1.006276×10^{-2} eV, or 2.157141×10^{6} times the natural linewidth** (Section 3). **Sixth, the separator is whether the recoil is taken by an atom or by a crystal——nothing was "set to zero". One formula returns two answers according to whether the mass in its denominator is one atom or one crystal** (Section 4). **Keywords**: Mössbauer effect, recoilless resonant absorption, recoil energy, natural linewidth, gamma ray, iron-57.

Scope of this paper (scope note): **No new theorem or law is claimed——the formula for recoil energy, the relation between lifetime and natural linewidth, and recoilless resonant absorption (Mössbauer 1958) are all standard.The recoilless fraction is not computed——the probability that a crystal takes the whole recoil (the Debye--Waller factor) and its temperature dependence are not treated. Only the two ends, one atom and one crystal, are examined.Nuclear structure is not discussed——isomer shift, quadrupole splitting and magnetic splitting are not the subject.No experiment is designed——how sources are made, what detectors are used and how the drive is built are not entered into.Representative values are used——14412.9 eV, a mean life of 141.1 ns and a crystal of 1 mg are representative, not measurements of a particular sample.Relation to earlier papers**: **Paper 336 counted the number 32768 inside a wristwatch and measured a clock's accuracy in parts per million (10^{-6})——this paper looks at the same question, how finely something can be measured, on a nuclear line, and counts how a resolution of 10^{-13} follows from the recoil being taken by a crystal rather than an atom.**What is added is **setting the recoil of an atom and of a crystal side by side in one formula**, **confirming to 10 digits that their ratio is the ratio of the receiving masses**, **deriving the speed corresponding to one linewidth**, and **placing the separator on who takes the recoil**.

1. Notation and the Question

Setting: **a nucleus of mass M at rest emits a gamma ray of energy E. Conservation of momentum makes the nucleus take a recoil.**

$$E_r = \frac{E^2}{2Mc^2}, \qquad \Gamma = \frac{\hbar}{\tau}$$

Here Γ is the natural width of a level of lifetime τ. Both the emitter and the absorber take a recoil, so the two lines sit $2E_r$ apart.If E_r exceeds Γ, they do not overlap.

Question: **is resonant absorption blocked by recoil itself, or by the smallness of the mass that takes it?**

2. With Free Atoms the Lines Do Not Overlap

Computation 2.1: **the recoil and natural width for the 14412.9 eV line of iron-57 were derived.**

quantity	value
rest energy of the nucleus Mc^2	5.303498×10^{10} eV
recoil taken by one atom E_r	1.958440×10^{-3} eV
natural width Γ (mean life 141.1 ns)	4.664861×10^{-9} eV
recoil ÷ natural width	4.198282×10^{5}
resolution Γ / E	3.236588×10^{-13}

The recoil is 4.198282×10^{5} times the natural width. Measured in linewidths, the emitted and absorbed lines stand four hundred thousand widths apart.

Computation 2.2: shifting the line by one natural width takes 9.703046×10^{-5} m/s, that is 0.097030 mm/s. Shifting it by the recoil takes 40.7361 m/s.

> **Observation 2.3**
>
> **being narrow and failing to match are two things.The resolution 3.236588×10^{-13} is seven orders finer than the parts per million in which clock accuracy is usually measured. It is precisely this narrowness that lets a recoil as small as 1.958440×10^{-3} eV throw the line completely off——the narrowness is both the virtue and the reason the resonance breaks.**

3. Changing Who Takes It

Computation 3.1: the mass in the denominator of the same formula was changed from one atom to a 1 mg crystal.

receiver	recoil E_r	against the natural width
one iron-57 atom	1.958440×10^{-3} eV	4.198282×10^{5}
a 1 mg crystal (1.057715×10^{19} atoms)	1.851577×10^{-22} eV	3.969200×10^{-14}

The ratio of the two recoils is 1.057715×10^{19}, agreeing to 10 digits with 1 mg divided by the mass of one iron-57 atom.

Observation 3.2

the recoil has not become zero.When the crystal takes it, momentum is still conserved and a recoil energy of 1.851577×10^{-22} eV is genuinely there. All that changed is the mass in the denominator——and being 3.969200×10^{-14} of the natural width, it no longer keeps the lines apart.

Computation 3.3: in a gas of free atoms at 300 K, thermal Doppler broadening is 1.006276×10^{-2} eV, or 2.157141×10^{6} times the natural width.

Observation 3.4

one reason acts twice.Recoil and thermal motion both follow from a single atom being free to move. An atom built into a crystal moves alone in neither respect——one operation, making it a solid, removes both obstacles at once.

4. The Separator

Observation 4.1

the separator is whether the recoil is taken by an atom or by a crystal.There is one formula, and the only thing moved is the mass in its denominator. With one atom the recoil is 4.198282×10^{5} natural widths; with one crystal it is 3.969200×10^{-14}——the two answers come not from a difference of mechanism but from a difference of receiver.

Observation 4.2

beside Paper 336.Paper 336 counted the number inside a wristwatch and measured accuracy in parts per million. The resolution here is 3.236588×10^{-13}, seven orders finer——the same question, how finely something can be measured, ends in a dividing circuit for quartz and in the mass that takes the recoil for a nucleus.

Observation 4.3

what is not said.The fraction of events in which the crystal takes the whole recoil, which depends on temperature, is not computed, and hyperfine structure is not treated——what is shown is that the obstacle was not recoil itself but the smallness of the mass taking it.

5. Roll Call and Closing

1. **recoil 1.958440×10^{-3} eV** (Computation 2.1): **one atom.**
2. **natural width 4.664861×10^{-9} eV** (Computation 2.1): **mean life 141.1 ns.**
3. **ratio 4.198282×10^{5}** (Computation 2.1): **no overlap.**
4. **resolution 3.236588×10^{-13}** (Computation 2.1): **seven orders finer than ppm.**
5. **one width is 0.097030 mm/s** (Computation 2.2): **the recoil takes 40.7361 m/s.**
6. **1.851577×10^{-22} eV for a crystal** (Computation 3.1): **same formula, other denominator.**
7. **3.969200×10^{-14} of the width** (Computation 3.1): **no longer in the way.**
8. **ratio matches the masses to 10 digits** (Computation 3.1): 1.057715×10^{19}**.**
9. **2.157141×10^{6} in a gas at 300 K** (Computation 3.3): **thermal motion, same reason.**
10. **atom or crystal** (Observation 4.1): **the separator; Paper 336.**

Closing: **What blocked nuclear resonant absorption was not the phenomenon of recoil.For the iron-57 line, the recoil taken by one atom, 1.958440×10^{-3} eV, is 4.198282×10^{5} times the natural width, and the line is thrown completely off.Change the denominator of the same formula to a 1 mg crystal and the recoil becomes 1.851577×10^{-22} eV, 3.969200×10^{-14} of the width, the two recoils standing in the ratio of the receiving masses, 1.057715×10^{19}, to 10 digits——the recoil did not vanish; the receiver changed.The separator is whether the recoil is taken by an atom or by a crystal.Placed among the earlier papers——the question Paper 336 measured in parts per million was counted here on the 10^{-13} side.To be honest——the fraction taken wholly by the crystal and its temperature dependence were not computed; only the two ends were examined.**

References

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