Acceleration anomaly in a classical physics approach of Bloch gravity atomic spectrometry

Han Geurdes
Pensioner,
Orcid:0000-0002-7487-1875
C vd Lijnstr 164 2593NN, Netherlands
han.geurdes@proton.me

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Abstract

Describing Boron atoms in a Bloch vertical laser lattice experiment, with a classical physics equation gives an anomaly in the acceleration. We found an "out of nowhere" increase in g is $\Delta g \approx 0.393\, g$ under certain conditions.

1 Introduction

The use of atomic spectrometry in gravitation research is becoming increasingly important. A sensitivity of 1.4×10^{-8} g at 1 second can be obtained [1]. In our present work, the paper of Kuz'menko [2] is our starting point. Kuz'menko claims that the Bloch-type gravitation research can be interpreted as a case of time non-invariance. If we treat a Boron atom gas with classical physics, we find under certain conditions, a possible increase in g of $\Delta g \approx 0.393\, g$. Perhaps this result points in the direction of Kuz'menko's criticism about time invariance. Apart from that the present result appears interesting enough because a gas with a low density of Boron atoms can be approximately described classically. The example of ^{10}B and ^{11}B serves as a computational example associated with empirical reality. The question is how such an intrinsic increase can be justified.

2 Model

Let us look at the section on Bloch experiments in [2]. Here, cold atoms with mass m are trapped in a lattice of laser beams with wavelength λ. It is stated in [2] that the height of the atoms along the vertical axis is equal to

$$x_0 = \frac{h^2}{2m^2\lambda^2 g} \tag{1}$$

Equation (1) is, considering units, a valid physics equation. It is the consequence of the recoil kinetic energy, $E_R = h^2/(2m\lambda^2)$, which is equal to mgx_0. Nevertheless, let's assume that the function representing height $x(t)$ varies within a small interval in x_0. The interval is $\mathcal{X} = \{x \in \mathbb{R} \,|\, x_0 - \epsilon \leq x \leq x_0\}$. Here, the ϵ is a relatively small positive number. Equivalently, the time t is such that $x(t) \in \mathcal{X}$. As required, a low density of atoms is assumed.

Then we may have the following expression for a t with $x(t) \in \mathcal{X}$ and $v_0 > 0$ the initial velocity in this time frame, when $t = t_{max}$

$$x(t) = v_0 t + \frac{g}{2} t^2 = \frac{h^2}{2m^2\lambda^2 g} \tag{2}$$

The time set we consider for $x(t) \in \mathcal{X}$, is $\mathcal{T} = \{t \in \mathbb{R}^+ \,|\, 0 < t \leq t_{\max}\}$. This implies $x(t) - x_0 < 0$. The $t_{\max}$ is defined in (7) below.

The equation (2) can obviously also give,

$$t^2 + \frac{2v_0}{g} t - \frac{h^2}{m^2\lambda^2 g^2} = 0 \tag{3}$$

Which, using the abc formula, leads us to

$$t = \frac{v_0}{g}\left(-1 \pm \sqrt{1 + \frac{h^2}{m^2\lambda^2 v_0^2}}\right) \tag{4}$$

Now, we may have from the left-hand side of equation (2)

$$\frac{dx}{dt} = \dot{x} = v_0 + gt \tag{5}$$

Let's assume that the

$$\xi = \frac{h^2}{4m^2\lambda^2 g} \in \mathcal{X} \tag{6}$$

is an element of $\mathcal{X}$ and $\xi < x_0$. In our computations we have approximately $\mathcal{X} = (33, 147)$ in units of μm. The interval of fluctuations is such that $\epsilon \geq \frac{x_0}{2}$. This is an example of attaching numbers to a computation.

To continue, $x(t)$, for t in the appropriate sub-interval of $\mathcal{T}$, can be equal to ξ. In our computations with ^{10}B and ^{11}B we have $\xi \approx 123\mu$m.

2.1 The time interval

When $x(t) \in \mathcal{X}$, we equivalently have $t \in \mathcal{T}$, and, $\mathcal{T} = \{t \in \mathbb{R}^+ \,|\, 0 < t \leq t_{\max}\}$ and for completeness from (4)

$$t_{\max} = \frac{v_0}{g}\left(-1 + \sqrt{1 + \frac{h^2}{m^2\lambda^2 v_0^2}}\right) \tag{7}$$

And so, from (5) and (7) together with $x(t) \in (\xi - \epsilon', \xi + \epsilon') \subset \mathcal{X}$. It follows, via $\dot{x}(t) = v_0 + gt \leq v_0 + gt_{max}$, that

$$\dot{x}(t) \leq v_0 \sqrt{1 + \frac{4g}{v_0^2} x(t)} \tag{8}$$

There is a $\alpha \geq 1$, constant in time, such that, $t \in \mathcal{T}$ gives

$$\alpha \dot{x}(t) \approx v_0 \sqrt{1 + \frac{4g}{v_0^2} x(t)} \tag{9}$$

for $t \in \mathcal{T}' \subset \mathcal{T}$.

2.2 Differential equation

Let us approximate the square root in the first-order term; $\sqrt{1+y} \approx 1 + (y/2)$. Equation (9), is then approximately equal to

$$\alpha \dot{x}(t) \approx v_0 + \frac{2g}{v_0} x(t) \tag{10}$$

This can be justified by $x(t)$ around x_0 in (5). Therefore, the singular solution is

$$x_S(t) \approx f \, \exp\left(\frac{2gt}{\alpha v_0}\right) \tag{11}$$

Variation in f leads in interval $(0, t)$ to $\dot{f} \exp\left(\frac{2gt}{\alpha v0}\right) = \frac{v_0}{\alpha}$. Then,

$$x(t) \approx \frac{v_0^2}{2g} \left(\exp\left(\frac{2gt}{\alpha v0}\right) - 1 \right) \approx \frac{v_0^2}{2g} \left(\frac{2gt}{\alpha v_0}\right) \tag{12}$$

And so, $x(t) \approx \frac{v_0 t}{\alpha}$. If we then look at $x(t)$ closely around ξ of equation (6), and τ is a time parameter in $\mathcal{T}' \subset \mathcal{T}$, then

$$\alpha \approx \frac{4 v_0 \tau m^2 \lambda^2 g}{h^2} \tag{13}$$

It must be noted that α in (8) and (9), is independent of time. Therefore, in an experiment the $v_0 \tau$ is selected so that $x_0(\tau) = v_0 \tau$ is in $\mathcal{X}$.

2.3 Acceleration $\ddot{x}(t)$

The previous subsections imply, via (9),

$$\alpha \ddot{x}(t) \approx \frac{v_0}{2\sqrt{1 + \frac{4g}{v_0^2}}} \frac{4g}{v_0^2} \dot{x}(t) = \frac{1}{\alpha} 2g \tag{14}$$

Hence, at a certain point in time where $x(t)$ closely approximates ξ as given by (6), the g acceleration is

$$\ddot{x}(t) \approx \frac{2g}{\alpha^2} \tag{15}$$

The $x(t)$ is close to ξ

2.3.1 What is the physics

The question we raise here is; "Is it possible to have $\sqrt{2} > \alpha > 1$?" Because, if so, $\frac{\sqrt{2}}{\alpha} > 1$, and so, $\ddot{x} > g$. Therefore, a question can be raised about where the increase in acceleration of certain atoms in the gas came from.

The criterium is to compute $x_0(\tau) = v_0\tau$ and see if $x_0(\tau) \in \mathcal{X}$. The inequality we inspect is

$$\frac{h}{\sqrt{g}}\sqrt{(2^{1/2})/4} > \sqrt{v_0\tau}\, m\lambda > 2^{-1}\frac{h}{\sqrt{g}} \tag{16}$$

The estimate is $\sqrt{v_0\tau}\, m\lambda \approx (h/\sqrt{g})(2^{-1} + \sqrt{(2^{1/2})/4}\,)/2$. We take Boron atoms $m \approx 1.7934 \times 10^{-26}\,(kg)$ and $\lambda = 5.32 \times 10^{-7}\,(m)$. The evaporation energy for 1 mole of Boron is 508 kJ. The constants we work with are $g = 9.8\,(ms^{-2})$ together with Planck's constant $h \approx 6.6261 \times 10^{-34}\,(kgm^2s^{-1})$. According to the computations in the section below, from (1), is $x_0(0) \approx 2.461 \times 10^{-4}$. The interval $\mathcal{X}$ is more exactly defined by $(2.461 \times 10^{-4} - \epsilon, 2.461 \times 10^{-4})$. The subset $\mathcal{X}' \subset \mathcal{X}$ for $\tau \in \mathcal{T}'$ contains $x_0(\tau)$. The code, section-2.3.2, below gives $x_0(\tau) \approx 1.474\times10^{-4}$. The minimal eps defining $x_0(\tau) \in \mathcal{X}$ is $\epsilon_{\mathrm{mi}} \approx 9.866\times10^{-5}$. Hence. an epsilon such as e.g. $\epsilon \approx 9.766 \times 10^{-5}$, gives indeed, $x_0(\tau) \in \mathcal{X}$.

2.3.2 Code

In order to have easy computations, the following R code describes the equation numerically.

```
h<-6.6261e-34
m<-1.7934e-26
lam<-5.32e-7
g<-9.8
fc<-(sqrt((2^(0.5))/4)+(1/2))/2
x0<-h^2/(2*g*m^2*lam^2)
fchg<-fc*h/(sqrt(g))
v0t<-(fchg/(m*lam))^2
epsmi<-x0-v0t
alf<-(4*v0t*m^2*lam^2*g)/(h^2)
print(x0)
```

```
print(v0t)
print(epsmi)
print(alf)
dg<-1.393
declpr<-dg*g/2
declpr<-declpr*((3.317e-3)^2)
x10b<-v0t-declpr
decl<-declpr/dg
x11b<-1.40e-4
x11b<-x11b-decl
print(x10b)
print(x11b)
stop("x")
```

3 Conclusion and discussion

Because $x_0(\tau) \in \mathcal{X}$ we found that in $x(t) \approx \xi$,

$$\ddot{x}(t) \approx \left(\frac{\sqrt{2}}{\alpha}\right)^2 g > g \tag{17}$$

This is so because it turned out that, $\sqrt{2} > \alpha > 1$ is possible with $x_0(\tau) \approx 1.47 \times 10^{-4} \in \mathcal{X}$. In fact $\alpha \approx 1.1982$. Hence, $\frac{\sqrt{2}}{\alpha} \approx 1.1803$ which gives $\ddot{x} \approx 1.3931\, g$, and so an increase of $\Delta g \approx 0.3931 g$ is found. Let's take e.g. $\tau \approx 33.17\mu$s. And so $v_0 \approx 4.432$ meters per second. This is a valid velocity in a classical treatment. The initial velocity $v_0 > 0$ is possible. Therefore, an approach with $x(t) = v_0 t + (g/2)t^2$ is justified. Furthermore, the attention is directed to the part of the interval $\mathcal{X}$, where $\xi \approx 123\mu$m can be found. The size of $\mathcal{X}$ is perhaps, however, not physical. That's nevertheless unimportant for the principle of a $\Delta g > 0$. Of course, to increase the approximation the ξ can be chosen closer to x_0. A $\Delta g > 0$ can be derived. The example of $\xi = \frac{x_0}{2} \approx 123\mu$m serves the purpose of setting up a calculation in a realistic empirical setting.

Despite considerations of the degree of approximation, the following question can be raised. Where does such an increase Δg of $\ddot{x}$ come from? It cannot be something in the surroundings of the Boron Bloch interferometer. In addition and quite importantly, is an experiment possible?

3.1 Experiment setup

Suppose, we take a 1:1 mixture of ^{10}B and ^{11}B. Starting from the position below ξ, e.g. at 33μm. Then for ^{11}B it will be a little bit more difficult to reach ξ than for ^{10}B. This means that a setup can be created where ^{10}B can obtain the alleged increased acceleration $g + \Delta g$, while the ^{11}B can not.

First, we turn on the laser lattice during approximately 4.1μs and let the mixture of ^{10}B and ^{11}B have a $v_0 \approx 4.432$m/s. Then, secondly, turn off the lattice during $\delta t = 3.317$ms. When the lattice is turned off, the initial velocity is zero for both ^{10}B and ^{11}B in free fall.

The computations, see the section-2.3.2, labeled Code, show that the ^{10}B, starting from 123μm will have arrived at $x(^{10}B) \approx 4.793 \times 10^{-5}$m, i.e. approx 48$\mu$m. The ^{11}B, starting from 120μm, will have arrived at $x(^{11}B) \approx 6.609 \times 10^{-5}$m, i.e. 66$\mu$m. In $\delta t = 3.317$ms, the ^{10}B arrive at 48μm. The ^{11}B arrive at 66μm in that same time. If after $\delta t = 3.317$ms at 48μm the ^{10}B and ^{11}B are counted, there will be more ^{10}B than ^{11}B.

Obviously, the absorption/emission of photons by Boron atoms in the laser lattice has been left out of consideration in this classical approach. The energy in eV at 532nm is approximately $E = \frac{6.582\times10^{-16}}{2\pi}\frac{2.998\times10^{8}}{5.32\times10^{-7}} \approx 0.0589$ eV. The absorption of a photon [1] is expected not to be very high. The classical physics approach of the atom as a little inert ball can be maintained in approximation. However, it can be questioned if it is a realistic way to set up a laser lattice for Boron.

Finally, the example with ^{10}B and ^{11}B is provided as a computational clue with a connection to physical empirical reality. Perhaps the ^{10}B and ^{11}B example is unrealistic in an actual experiment. Nevertheless, it enables an experimental setup to study this classical physics "out of nowhere" $\Delta g > 0$ in a low-density gas of atoms.

3.2 Time invariance

One thing is clear about the question of time invariance. Equation (2) is not time invariant. We have $t > 0$. A "$-t$" gives, via $x(t) = x_{\text{start}} + v_0 t + (g/2)t^2$, a different x than a "$+t$". Therefore, if, $x(t) = x_{\text{start}} + v_0 t + (g/2)t^2$, can be seen as a limit of quantum mechanics, time non-invariance appears to be related to the "out of nowhere" Δg.

References

[1] P. Clade, Bloch oscillations in atom interferometry, 2014. ffhal-00989685ff.

[2] V. Kuz'menko, On the time reversal noninvariance in quantum physics, DOI: 10.13140/RG.2.2.20696.19201, 2018.

[1] Looking at https://qedfusion.org/LIB/PROPS/PHOTON/borondata.html