Vibration Effects in a Magneto-gravitational UCN Trap and Some Thoughts on How to Make a Bigger and Better Trap

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Nov. 9, 2012

Presented at the workshop on next generation experiments to measure the neutron lifetime, Santa Fe, New Mexico, Nov. 9-10, 2012

Vibration Issues

- Vibration of the magnetic sources could “pump” the energy of neutrons to beyond the escape energy, cause neutron loss and a measured free neutron lifetime that is too short.
- Vibration could cause spin flips, which also gives a shorter measured lifetime.

Avoiding Majorana Spin Flips

$$\frac{dB/dt}{B} \ll \frac{\mu |B|}{\hbar}$$

$$\frac{dB}{dt} = \mathbf{v}\cdot\nabla B + \frac{\partial B}{\partial t}$$

This criterion is satisfied for reasonable vibrations

Simple 1-D model

- Motion in *z* only, gravity, exponential dependence of field with *z*, ignore holding field, vibration in *z*

$$B(z) = B_0 e^{-kz} \longrightarrow B(z) = B_0 e^{-k|z + d\sin(\omega t + \phi)|}$$

$$\frac{dv_z}{dt} = \frac{k|\mu|}{m} B_0 e^{-k|z + d\sin(\omega t + \phi)|} - g$$

$$\frac{dz}{dt} = v_z$$

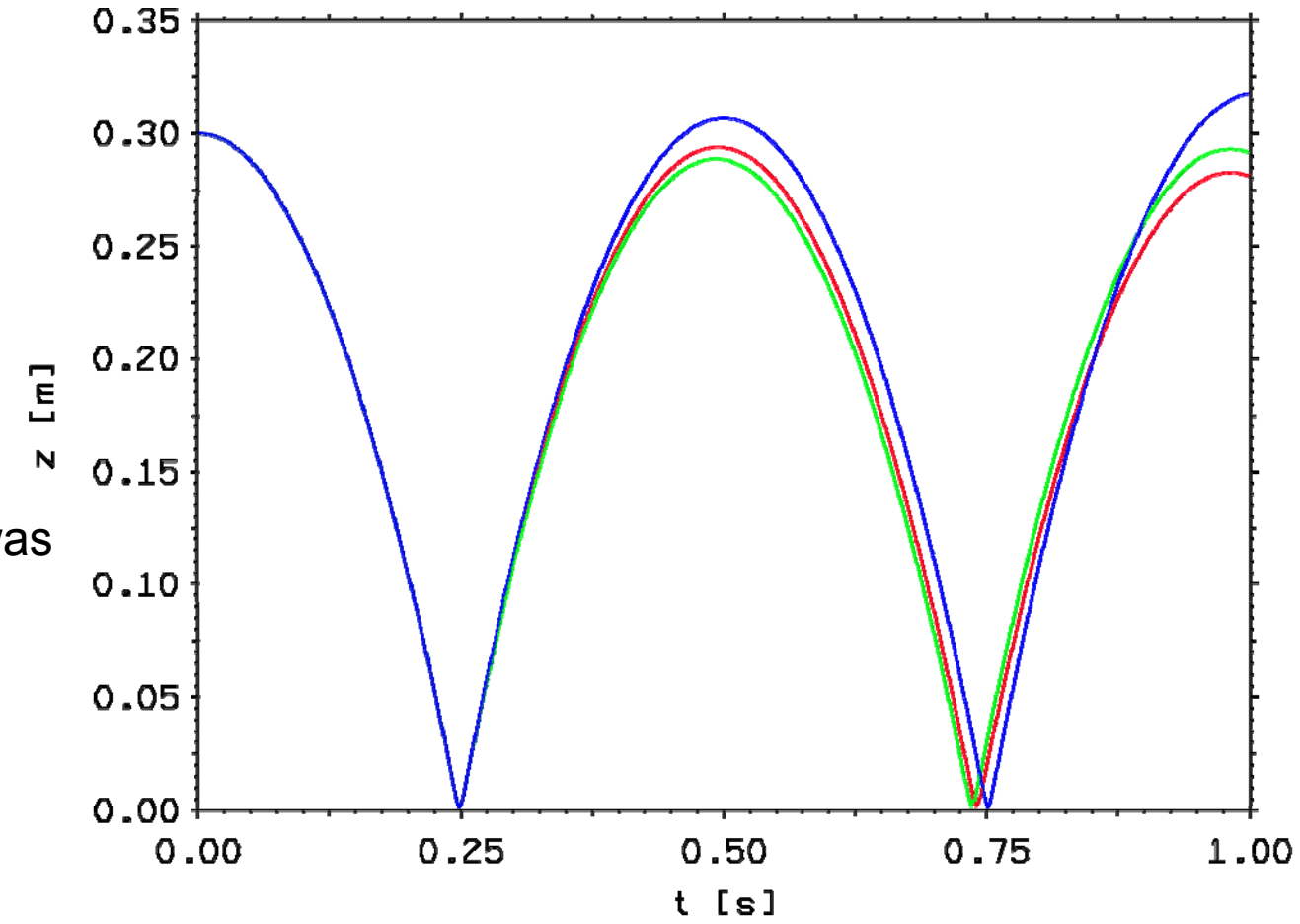
Symplectic Leapfrog with Time Dependence

```
c  Algorithm has half-drift, half-kick, full time step,
c half-kick, half drift
      t1=ti
c  First half-drift
      z2=zi+0.5d0*vi*dt
      v2=vi
c  First half-kick
      az=accel(k,g,b0,d,omega,phi,muoverm,z2,t1)
      z3=z2
      v3=v2+0.5d0*az*dt
c  Full time step
      t2=t1+dt
c  Second half-kick
      az=accel(k,g,b0,d,omega,phi,muoverm,z3,t2)
      z4=z3
      v4=v3+0.5d0*az*dt
c  Second  half-drift
      z5=z4+0.5d0*v4*dt
      v5=v4
c  Returned values
      tf=t2
      zf=z5
      vf=v5
      efoverm=0.5d0*vf**2+muoverm*b0*exp(-k*(zf+d*sin(omega*tf+phi)))+
     &g*zf
      return
      end
```

Numerical results

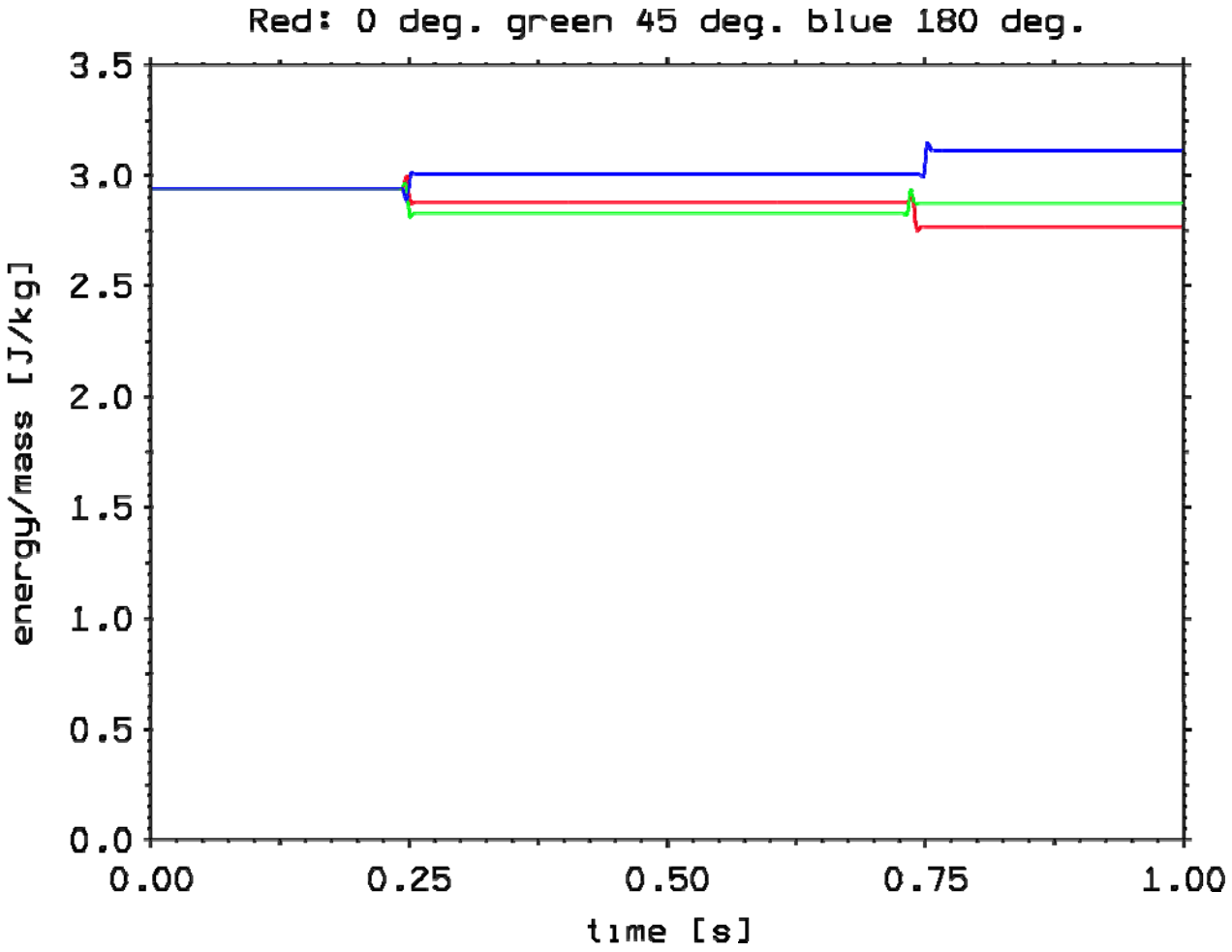
λ=0.02 m,
B_0=1 T,
d=10^{-4} m,
f=100 Hz
ω=2πf

The neutron was dropped from z=0.3 m with zero velocity



Plots of z vs. t for various phases. Red: 0 deg. ; green: 45 deg., and blue: 180 deg.

Energy vs. Time



Discussion

- Increase in energy observed with some phases in 2-D model is basically a resonance effect
- Hypothesis: resonance much weaker and less likely with 3-D motion
- Should be easy to check with the simplest 3-D model: whole trap vibrates with same amplitude, phase, direction

Simple 3-D model

- Vibrational motion in one direction everywhere with same amplitude

Let $$|\mathbf{B}(x,y,z)| = f(x,y,z)$$
$$\nabla|\mathbf{B}(x,y,z)| = \mathbf{F}(x,y,z)$$

Then

$$f(x,y,z) \rightarrow f\left[x + d_x(\sin\omega + \phi), x + d_y(\sin\omega + \phi), z + d_z(\sin\omega + \phi)\right]$$
$$\mathbf{F}(x,y,z) \rightarrow \mathbf{F}\left[x + d_x(\sin\omega + \phi), x + d_y(\sin\omega + \phi), z + d_z(\sin\omega + \phi)\right]$$

More Realistic Simple 3-D model

- Vibration amplitude and phase of magnetic field sources is a function of location, according to vibrational modes. May have more than one mode at one time.
- Field model now becomes very complicated
- Hope we don't need to go to this level of realism
- Might be possible to use some kind of perturbation approximation?

Bigger, Better, and More Expensive Magnetio-Gravitational Trap

- Same idea of using a truncated torus and making confining field sources follow the flux lines of the holding field, then no field zeros since the holding field and confining field are everywhere perpendicular
- Curved superconducting racetrack coils replace Halbach arrays. Trapping field 3-5 T, trapping depth of ~ 3 m
- No mechanical trap door- use bucking coil at bottom of trap to cancel field in a local region, neutrons go rhrough bore of coils.
- Ramp bucking coil down to zero current in ~ 1 minute to close the trap door.

Superconducting U-Tube (July 2005)

- Guide-field coils not shown- would be circular air-core windings in a toroidal array around U tube. Iron yoke to carry guide-field flux across the top.
- Difficulties:
  - cryostat, cold/warm bore issues.
  - closable neutron fill port
- Try same basic idea but with permanent magnets for trapping field.