Gravitational Measurements on Charged Particles

Can it be done?

A historical Excursion

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PS200 / AD-1/ AD-4

(acting as investigative reporter)

One Experiment speaks more than a thousand words:

PLEASE DO NOT TAKE AWAY

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16 January, 1986

PLEASE MAKE A PHOTOCOPY

A MEASUREMENT OF THE GRAVITATIONAL ACCELERATION OF THE ANTIPROTON

Universita di Pisa
Los Alamos National Laboratory
Rice University
Texas A&M University
Universita di Genova
Kent State University
Case Western Reserve University
CERN
NASA/Ames Research Center

GALILEO, *Discorsi e Dimostrazioni Matematiche intorno à Due Nuove Scienze Attenenti alla Mecanica e i Movimenti Locali*. . . . Leyden, 1638. *Ed. Naz.* 8.108-9

SIMPLICIO. Ma chi posasse la maggior sopra la minore?

SALVIATI. Le accrescerebbe peso, quando il suo moto fusse più veloce: ma già si è concluso che quando la minore fusse più tarda, ritarderebbe in parte la velocità della maggiore, tal che il lor composto si moverebbe men veloce, essendo maggiore dell' altra, che è contro al vostro assunto. Concludiamo per ciò, che i mobili grandi e i piccoli ancora, essendo della medesima gravità in spezie, si muovono con pari velocità.

SIMP. Il vostro discorso procede benissimo veramente: tuttavia mi par duro a credere che una lagrima di piombo si abbia a muover così veloce come una palla d' artiglieria.

SALV. Voi dovevi dire, un grano di rena come una macina da guado. Io non vorrei, Sig. Simplicio, che voi faceste come molt' altri fanno, che, divertendo il discorso dal principale intento, vi attaccaste a un mio detto che mancasse dal vero quant' è un capello, e che sotto questo capello volesse nasconder un difetto d'un altro, grande quant' una gomona da nave. Aristotele dice: 'Una palla di ferro di cento libbre, cadendo dall' altezza di cento braccia, arriva in terra prima che una di una libbra sia scesa un sol braccio'; io dico ch' ell' arrivano nell' istesso tempo; voi trovate, nel farne l'esperienza, che la maggiore anticipa due dita la minore, cioè che quando la grande percuote in terra, l'altra ne è lontana due dita: ora vorreste dopo queste due dita appiattare le novantanove braccia d'Aristotele.

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Phase 0:
Wind is stronger than gravity
Auxiliary forces need shielding

- **Free fall environment must suppress all other stronger forces**

Can this really be done with charged particles?

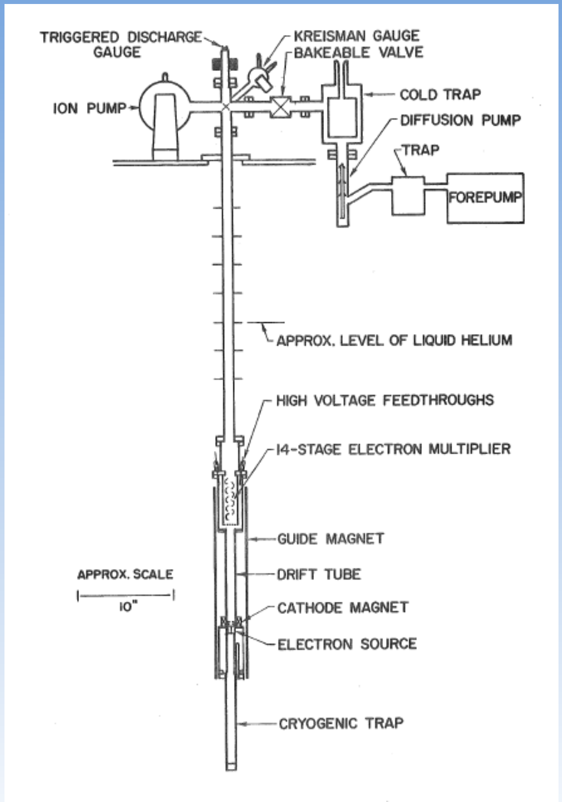
We believed so (and may still do so)

First Attempts to Detect Gravity

PhD Thesis by Fred C. Witteborn at Stanford University (1965)

Free Fall Experiments with Negative Ions and Electrons

Measurements of the gravitational forces on free, negative ions and
<u>a demonstration of the feasibility</u> of making similar measurements on free electrons



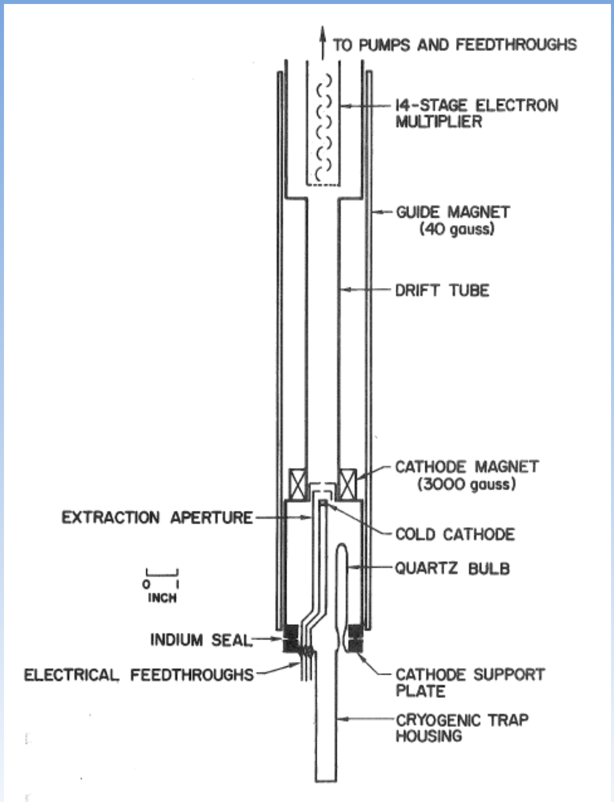
Goals:

Gravity on free ions

Feasibility of experiment on electrons

Detailed studies of all forces in addition to gravity

1965:
Mission accomplished
Design of final apparatus completed



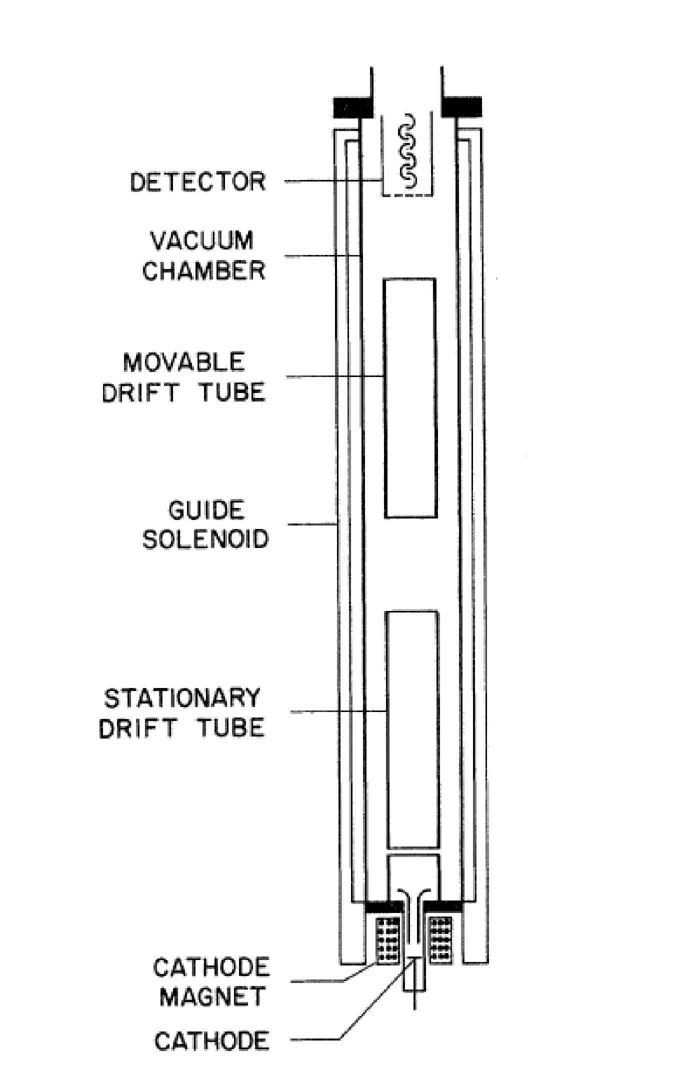
Witteborn's Thesis was followed in rapid Succession by two seminal papers kicking off many discussions and follow-up experiments:

Measurement of g_{eff} for Electrons

F.C. Witteborn, William M. Fairbank; Phys. Rev. Lett. 19 (1967) 1049; Experimental comparison of the gravitational force on freely falling electrons and metallic electrons

F.C. Witteborn, William M. Fairbank; Nature 220 (1968) 436 Experiments to determine the Force of Gravity on Single Electrons and Positrons

The basic Experiment



Launch electrons from cathode upwards towards a detector

Shield the charged particles from all external fields to a level lower than gravity by “drift tube”

Measure time of flight distributions

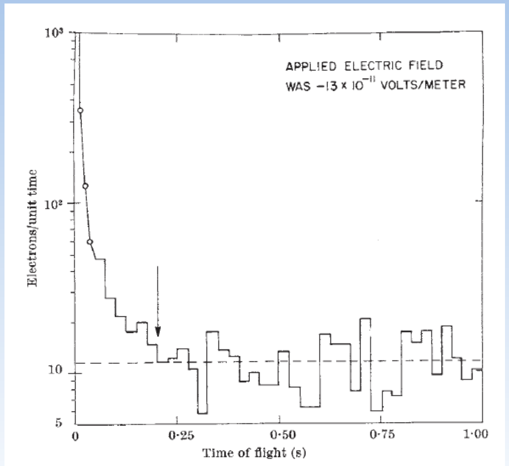
Extract g_{eff} from cut-off time

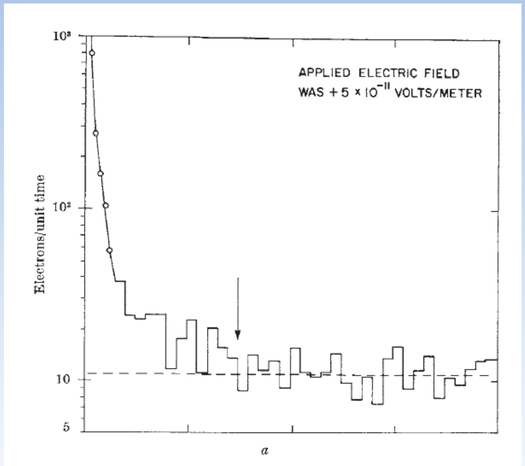
$$t_{max}=\sqrt{(2h/g_{eff})}$$

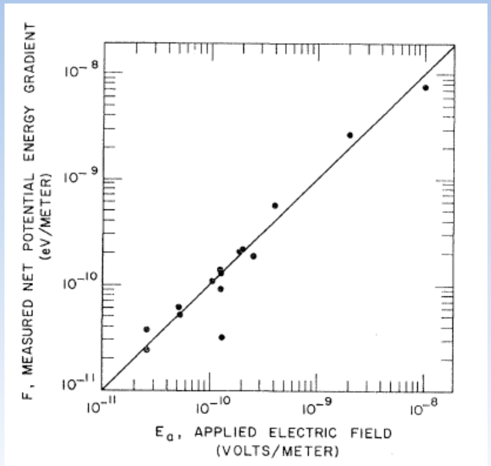
Apart from gravity unknown electrostatic or magnetic forces may act on the particles during their flight path and additional forces can be applied by running currents through the drift tube.:

$$t_{max} = \sqrt{2mh/|(mg + qE_{amb} + qE_{app})|}$$

Measuring t_{max} for several values of E_{app} allows to extract $(mg + qE_{amb})$ of the particle under investigation



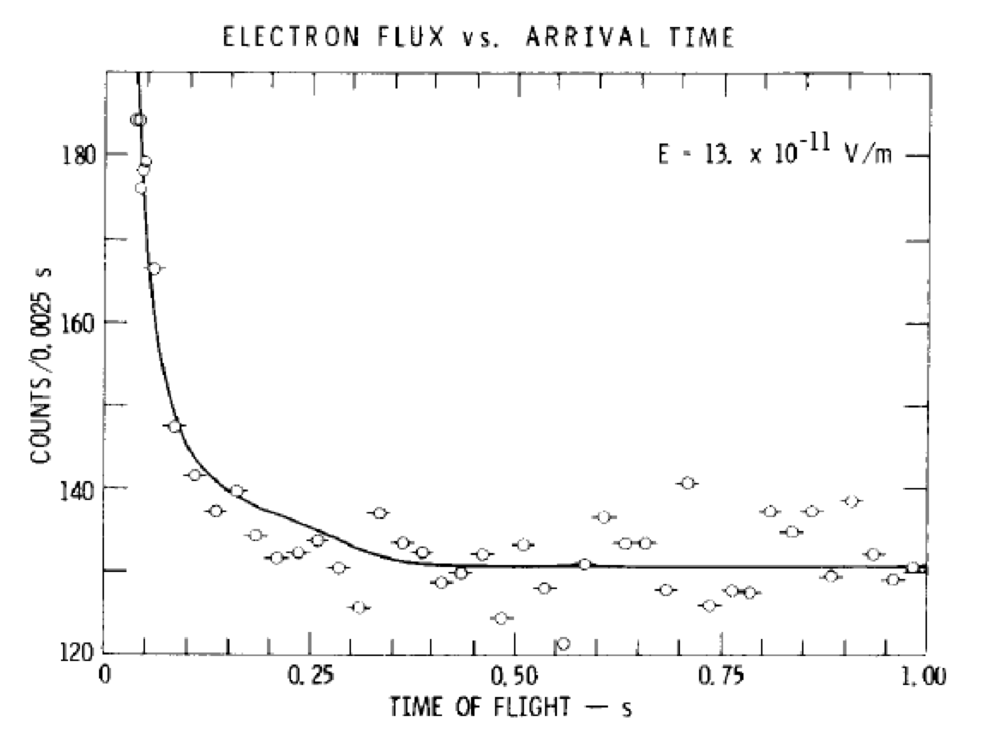




Five parameter fit to the TOF distributions

(a) Constant noise background: Background electron counting noise limits the precision with which t can be determined;

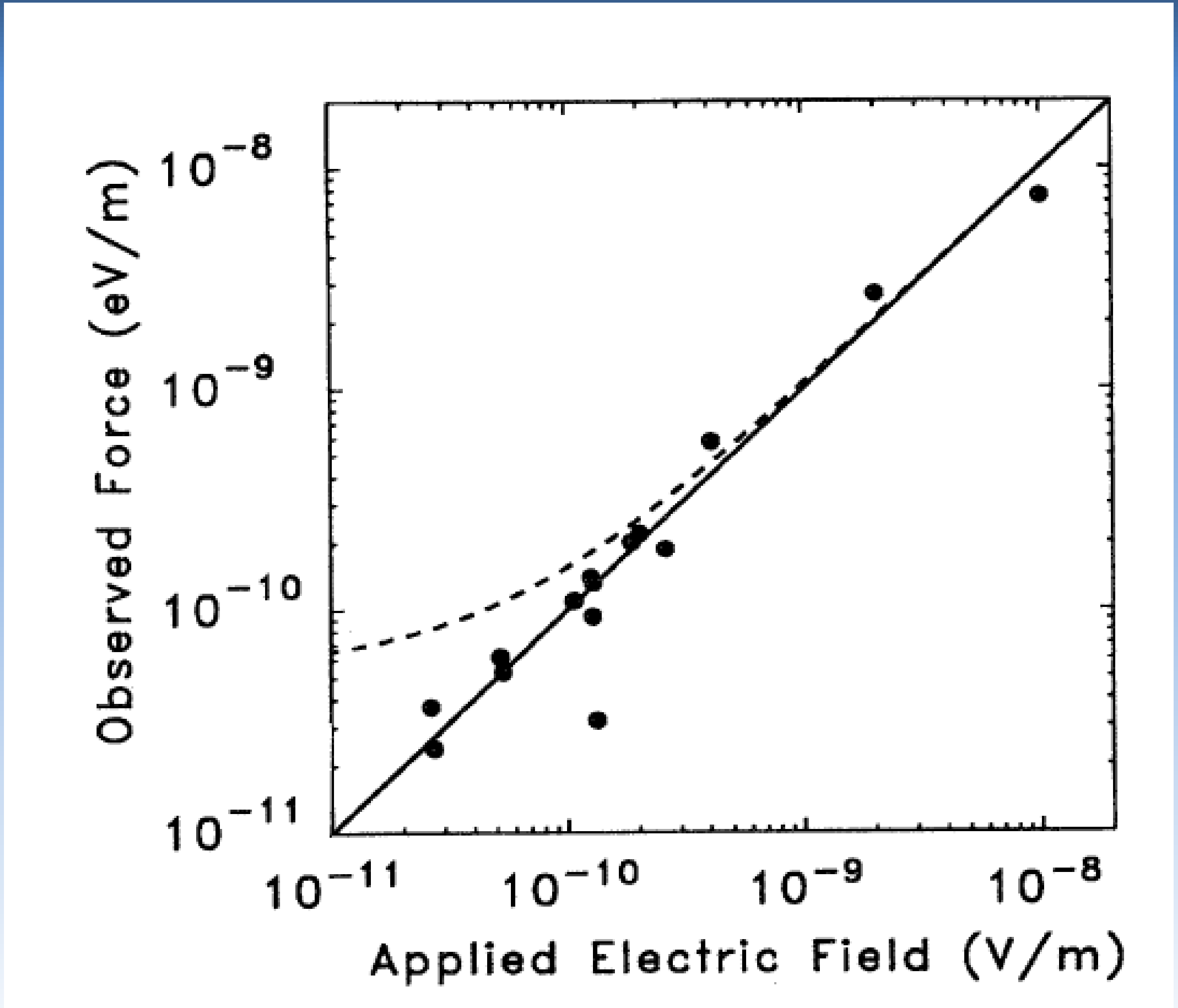
(b,c) Two parameters account for the energy distribution of the electrons as they enter the tube. One is related to the total number of electrons launched. The other accounts for cooling of the electrons via the Coulomb force.



(d) Another parameter accounts for delayed emission of electrons from potential traps along the Flight path.

(e) The fifth parameter is the desired constant force experienced by the electrons in the shielded portion of the drift tube.

For Electrons $mg + E_{amb} = 0.09\ g$



Explanation:

Charged particles within a metal tube will see electric fields due to:

Sagging of free electron gas (Schiff-Barnhill Effect)

$g_{eff} = g[1 - m_e Q/Me]$ *(M = mass, Q = charge of test particle)*

➔ *for electrons* $g_{eff} = 0$

➔ *for positrons* $g_{eff} = 2\,g$

(no measurements due to lack of source)

BUT they apparently did not see:

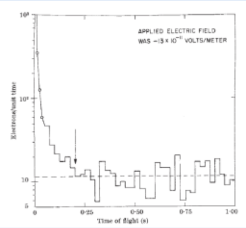
- **Compression of atomic lattice (Dessler et al. 1968)**

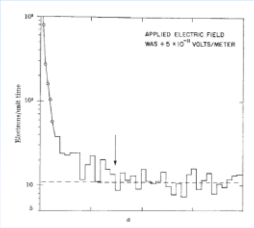
  DMRT ≅ 1836 SB

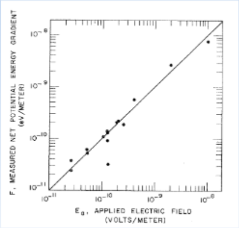
- **Fields from "Patches" in the crystal structure on the inner surface expected to of the order of 10^{-6} V/m**

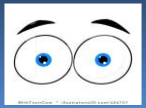
And:

We have not even talked about magnetic fields and all the other issues!







Let's take a closer Look 

Primary Papers:

F. C. Witteborn and W.M. Fairbank; Phys. Rev. Lett. 19 (1967) pp. 1049-52
Fred C. Witteborn, William M. Fairbank; Nature Vol. 220 (1968) pp. 436 – 440
F.C. Witteborn and W.M. Fairbank; Rev. Sci. Instrum. 48 (1977) pp. 1 – 11
J.B. Camp and F.C. Witteborn; Rev. Sci. Instrum. 64 (1993) pp. 894 - 896

Secondary Papers:

J.M. Lockhart, F.C. Witteborn, and W.M. Fairbank; LT14; (1975) p. 274-277
J.M. Lockhart, F.C. Witteborn, and W.M. Fairbank; Phys. Rev. Lett. 38 (1977) p. 1220
J.M. Lockhart, F.C. Witteborn, and W.M. Fairbank; Phys. Rev. Lett. 67 (1991) p. 283

Discussions by other groups:

T.W. Darling, F. Rossi, G.I. Opat, and G.F. Moorhead; Rev. Mod. Phys. 64 (1992) p. 237

Theses:

F.C. Witteborn (1965)
J.M. Lockhart (1976)
John Henderson (1987)
T.W. Darling (1989)
F. Rossi (1991)

Personal Interviews:

F.C. Witteborn
T.W. Darling

First Attempts to Detect Gravity

PhD Thesis by Fred C. Witteborn at Stanford University (1965)

Free Fall Experiments with Negative Ions and Electrons

Purpose: Measurements of the gravitational forces on free, negative ions and a <u>demonstration of the feasibility</u> of making similar measurements on free electrons

Detailed Description of original apparatus

Design considerations of:

- **Electrostatic effects (one electron charge at 5 meter distance = gravity)**
  - Schiff-Barnhill
  - Patch effect
  - Image charges on shield tube
  - Field penetration into the drift tube
  - Thompson EMF
  - Electron-electron interactions
- **Magnetic effects**
  - Requirement on maximum distance from axis $r \leq 0.01$ cm
  - Magnetic inhomogeneities only tolerable for ground state electrons
  - Temporal stability of magnetic field
- **Vacuum**

Magnetic fields effects:

Magnetic energy of an electron in a uniform magnetic field:

$E = 2\mu_B B(n + ½ + ½s \times g_s)$ $\mu_B = .93 \times 10\text{-}20$ erg/gauss

$g_s = 2.0023$

If B changes by 0.1 Gauss along the flight path:

$n > 1$ $\Delta E \geq 10^{-8}$ eV

$n = 0$, $s = -½$: $\Delta E \approx 4 \times 10^{-12}$ eV

SOLUTION: STATE SEPARATION AT THE SOURCE:

Apply magnetic field of 4000 Gauss in the cathode region:

Electrons with n>1 are accelerated into the drift tube and $\Delta t < 1$ msec

Electrons with $n = 0$, $s = -½$ are slightly retarded

OFF AXIS MOTION:

Charge at distance r from axis experiences Force $\boldsymbol{F} = q\boldsymbol{E}$, with $\boldsymbol{E} = q\boldsymbol{r}/4\pi\varepsilon_0 a^3$

ExB drift causes circular motion and therefore an additional magnetic moment $\mu_{orbital}$:

At $r = 5 \times 10^{-4}$ m $\mu_{orbital}$ is equal and opposite to anomalous magnetic moment

- ➔ restrict radius of electron beam in drift tube to $< 10^{-3}$ m
- ➔ useful cathode surface area for $B_{source} = 4000$ Gauss $r_{source} = 10^{-4}$ m

Vacuum Issues:

Interaction of electron with induced dipole moment of the helium atoms:

Potential energy of an electron near a helium atom is

$\alpha q2/(4\pi\varepsilon_0)^2 r^4 > 10^{-11}$ eV for $r < .7\ 10^{-5}$cm

➔ $p < 1 \times 10^{-10}$ Torr at 4.2 K

Apparatus needs to be cryogenic

(which also allows superconductive magnets)

Thermal Effects

Thomson EMF: $V_T = \sigma_T T$ ($\sigma_T \approx \mu$V/degree)

if drift tube would be in contact with helium bath we expect a temperature gradient of $0.34\ 10^{-3}$ °/cm

➔ $\Delta V = 0.34\ 10^{-3}$ °/cm × 100 cm × 1μV = $3.4\ 10^{-8}$ V

➔ Drift tube needs to be thermally contacted only at one point

Electron – Electron Interaction ➔ less than 1 e^- per pulse

Field Penetration into Drift Tube ➔ a/h << 1

Image Charges on Drift Tube ➔ $\delta r/r < 1\times10^{-4}$

Patch Effect

C. Herring, M. H. Nichols; Rev. Mod. Phys 21 (1949) 270

Variations in work function along a metal surface due to the crystalline nature of the surface: Typical variations are around +/- 0.1 V. For random distribution on a metal surface the potential on axis of a long cylinder is

$$\Delta\Phi = 0.06\ (a/r)\ \text{eV}$$

For a = 0.0045 cm and r = 2.5 cm $\Delta\Phi = 10^{-6}$ eV

Nature 220: "*experiments performed with a pilot model free fall apparatus 2 cm in diameter indicated that at 4.2 K the potential at the tube axis were uniform to about 10^{-9} or 10^{-10} eV".*

"…..We do not know what causes this apparent reduction in potential irregularities. We speculate that adsorbed gases may be smoothing out the variations."

!!!!!This apparent reduction is a factor of 3×10^{5}!!!!

and Fred Witteborn in the summary of his thesis writes:

Whatever the mechanism, it is an extremely fortunate one for the study of low energy charged particles.

Gravitational-Induced Electric Fields in Conductors

L.I. Schiff, M.V. Barnhill; Phys. Rev. 151 (1966) 1067

“It is apparent that each electron and nucleus in the metal must be acted on by an average electric field of such magnitude that it exactly balances its weight. Thus the quantum-mechanical expectation value of the electric field on an electron of mass *m* and charge *-e* must be *-(mg/e)****z***, where *g* is the acceleration of gravity and ***z*** is a unit vector in the upward direction. Since the electrons occupy most of the volume, the metal is nearly filled with this field, which would then be expected to be present also within a shield having the form of a metallic shell.”

“On the other hand, a nucleus of mass *M* and charge *Ze*, experiences an average electric field *+(Mg/Ze)****z***, and it might well be asked if the presence of this field alters the earlier conclusions. **It seems likely that it does not**, since the nuclei are well localized and occupy a very small fraction of the total volume, and moreover are separated from the region outside the metal by conduction electrons.”

A.J. Dessler, F.C. Michel, H.E. Rohrschach, G.T. Trammell; Phys. Rev 168 (1968) 737

"We have estimated the gravitationally induced electric field that should be found outside the conductor and we obtain a field with strength of order ***Mg/e*** (*M*=atomic mass) that is directed oppositely to the gravitational field (**upwards**). Schiff and Barnhill have previously estimated the electric field and obtained a value of ***mg/e*** (*m*=electron mass) that is in the **same direction** as the gravitational field."

"The two estimates are therefore **opposite in sign and differ by about five orders of magnitude (M/m)**. We believe that the large disagreement in the two estimates is due to an incorrect assessment by Schiff and Barnhill of the effect of lattice compressibility. Indeed, for an incompressible lattice we obtain their result."

"Recent experiments by Witteborn and Fairbank seem to show that the electric field within a copper shield is much smaller than the estimate presented in this paper and in fact is closer to the estimate given by Schiff and Barnhill. **The conditions of the experiment under which this result is obtained are not well understood."**

"The patch effect, which should determine the field in this experiment, also seems to be masked for some unknown reason. **It is possible that the same mechanism may be masking the field that should be present according to our calculations, and we believe that the question of the magnitude of the induced field is not yet experimentally settled."**

C. Herring; Phys. Rev. 171 (1968) 1361

…..attacks the problem in question ….by computing (or at least estimating) the effect of stress on the work function:

Electrostatic potential difference $\Delta\Phi$ between two points just outside the surface

$$\Delta\Phi = -\Delta\varphi + (m/e)\Delta\Psi$$

$\Delta\varphi$: difference in workfunction; $\Delta\Psi$: difference of gravitational potential

Essentially Herring reconciles SB with DMRT. Including the effect of gravity on the workfunction in the SB description he obtains the same result as DMRT.

"Careful experiments on the motion of charged particles in vertical metal tubes have been interpreted as indicating a total electric field much less than that expected from estimates of the strain derivative of the work function……
…according to the arguments presented here (and by DMRT), ***it seems inconceivable that the field induced purely by gravity can be this smal****l."*

"The proper interpretation of this large body of experimental data is thus a serious challenge for future work."

Room temperature experiments looking for stress-induced contact-potential variations in metals (Beams, Craig, French and Beams, and others) generally were consistent with DMRT

Rotating discs, vibrating (Kelvin) probes at room temperature and above.

Forces much larger than gravity were exerted on materials.

Many experiments observed significant influence on surface potentials by oxide layers and gas.

Witteborn F.C. and Pallesen M.R.; PRL 19 (1967) 1123 confirmed DMRT by inverting metal rods in gravitational field (at room temperature, in vacuum).

Mounting experimental evidence for the validity of Witteborn Fairbank:

- **WF obtained correct e/m for the electron in their analysis**
- **L.V. Knight used experiment to measure the anomalous magnetic moment of the electron. (Only possible if the electron energy was as low as WF claimed)**

Differences in experimental conditions do not allow a conclusive result

➔ Best test is to use the original apparatus (modified for operation at 300 K, 77 K, and below 20 K) with all other conditions identical to the original experiments to test the surface potential at different temperatures:

➔ J. M. Lockhart – PhD Thesis Stanford University 1976

Note on randomness and ordering:

Patches with +0.1 V and -0.1 V; Drift Tube Radius r = 2.5 cm; Patch dimension a = 1 μm

Witteborn: Random ordering results in $\Delta\Phi = 0.06\ (a/r)$ eV = 2.4×10^{-6} eV

C. Herring, M. H. Nichols; Thermionic Emission; Rev. Mod. Phys. 21 (1949) 185:
Calculated potential above surface with periodic ordering of patches in x and y (p. 262)

J.M.L: ➔ perfect checkerboard ordering: $\Delta\Phi = 10^{-82}$ eV
➔ Nearest Neighbor Ordering: $\Delta\Phi = 5.6 \times 10^{-12}$ eV

Lockhart: *"….ordering on this level is somewhat unlikely, …. it is not clear how the electroforming process could yield such ordering. But it is known that surface conditions can have a significant effect on the size of the patch fields. Surface shielding layer would most likely involve electron states based on the surface layer of copper oxide*
….effects of adsorbed gas are assumed to be small since the surface shielding layer appears to become inoperative above 9° K, while the change in the amount of adsorbed gas between 4.2° K and 9° K amounts to less than a monolayer"

Experimental Method and Set-Up used by Lockhart

Instead of the WF five parameter fit to obtain the average force from TOF distributions Lockhart establishes a set of experimental conditions and then takes data in a single run with no applied field and three different applied fields, and then takes the ratio of the count rate in each TOF interval to the count rate in the corresponding interval of the TOF spectrum obtained with no force applied.

- ➔ **Ratio in most cases only indicates if specific applied field depresses electron flux**
- ➔ **In low temperature regime (4.5° K < T < 20° K) ambient equivalent electric field in drift tube can be retrieved.**

Why??? "In cases where the ambient field is large (10^{-6} V/m) not enough information is available to construct the model of the potential distribution in the drift tube needed for the multi-parameter fit method used by WF"

"Much of the room temperature and LN2 temperature analysis is based on the assumption that an applied gradient will not produce an observable effect on slow electrons unless it produces a maximum potential which amounts to at least a few tenths of any potential fluctuation in the tube"

Basic Experimental Procedure

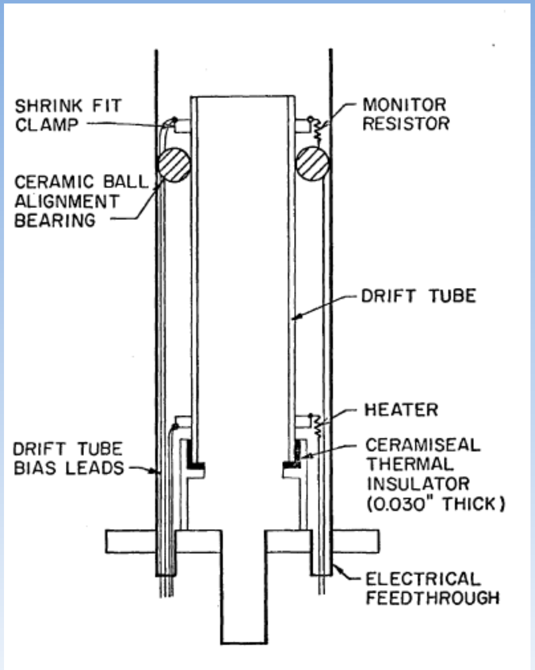
Measure at 300° K to search for possible shielding ➔ DMRT field

Measure at 77° K ➔ again no shielding observed

Measure at 4.2° K ➔ obtain data similar to that obtained by WF in 1967 !!

Next Step:

Modify apparatus to allow variable temperature by running current through drift tube



Thermally insulate tube

– main thermal conductance from drift tube leads

Add heating system

– 100 Ω metal film with small temperature coefficient

Add temperature monitor

– 650 Ω carbon resistor (LHe resistance 20 kΩ)

– 10^{-5} A produces only 2×10^{-6} W power

R [KΩ]	T [°K]	R [KΩ]	T [°K]
24	4.2	9.6	6.35
23	4.27	5.4	8.95
20.9	4.44	4.0	11.0

J.M. Lockhart et al.; Evidence for a Temperature-Dependent Surface Shielding Effect in Cu Physical Review Letters 38 (1977) 1220 - 1223

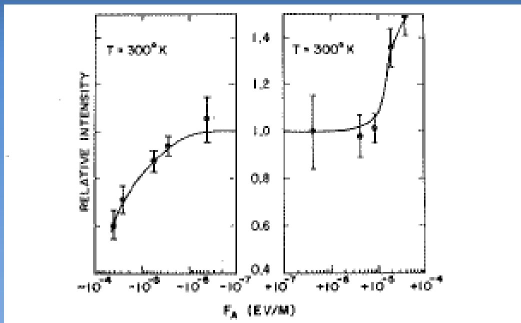


Fig. 3. A summary of data taken at room temperature.

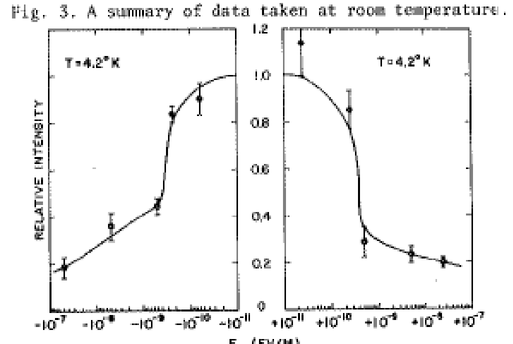


Fig. 4. A similar summary of data taken at 4.2°K.

<u>Preliminary Data (LT 14):</u>

At 4.2 K applied fields as low as 5 x 10^{-11} eV/m have strong (and symmetric) effect.

At 300 K 10^{-6} eV/m are needed. (Asymmetry not fully understood)

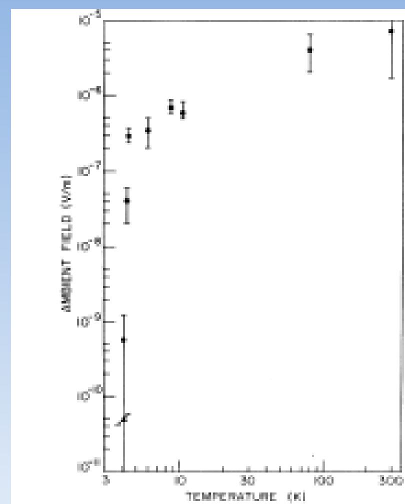
Full analysis of time-of-flight spectra:

$$t = \left(\frac{m}{2}\right)^{1/2} \int_0^h \frac{dz}{[W - ezE_{\mathrm{amb}}(z) - ezE_{\mathrm{app}} - mgz]^{1/2}},$$

$E_{amb}(z)$: Gravity induced and Patch Effect fields

E_{app} : constant field generated by current in DT

W : initial energy of particle at entrance of tube



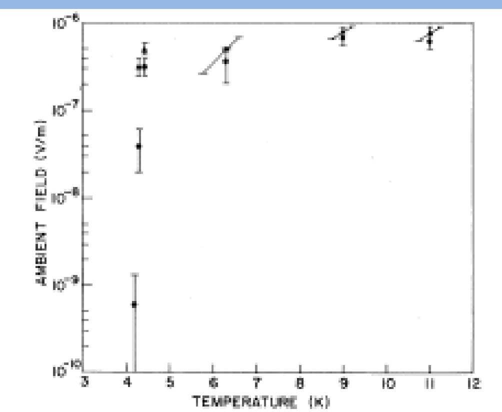


FIG. 3. An expanded view of the low-temperature results. The two sets of points are obtained using different analysis techniques, as described in the text.

$E_{amb}(z)$ = (6±7) x10^{-10} V/m @ 4.2K

(4±2) × 10^{-6} V/m @ 77 K

J.M. Lockhart et al. Evidence for a Temperature-Dependent Surface Shielding Effect in Cu Physical Review Letters 38 (1977) 1220 - 1223

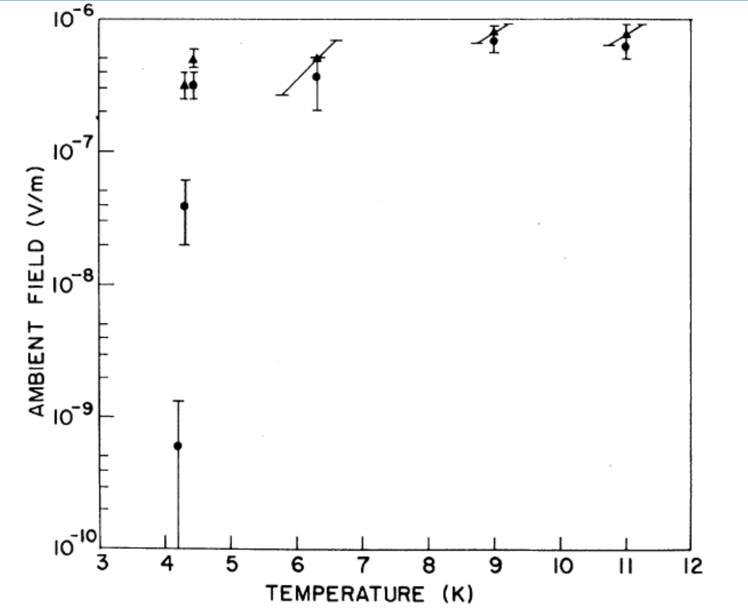


FIG. 3. An expanded view of the low-temperature results. The two sets of points are obtained using different analysis techniques, as described in the text.

2nd data set with constant applied field at different temperatures (Δ) agree???

BUT:
PRL 67 (1991) 283 ERRATA:
Helium leak in apparatus caused a higher back ground pressure of 8×10^{-9} to 4×10^{-8} Torr!

Above analysis assumes p < 2×10^{-10} … 4×10^{-8} would lead to dipole induced energy changes of 50% for electrons at 9.4×10^{-7} eV or less ….we clearly can place little confidence in ambient-field values corresponding to energy changes smaller than those caused by residual gas scattering.

Nevertheless:

These issues in no way affect the data or conclusions of the earlier 4.2 K measurements by Witteborn and Fairbank (p<<4×10^{-10} Torr).

It would thus seem that the evidence for the existence of a temperature-dependent shielding transition remains strong, but that the detailed nature of the temperature dependence cannot be ascertained from the data presented.

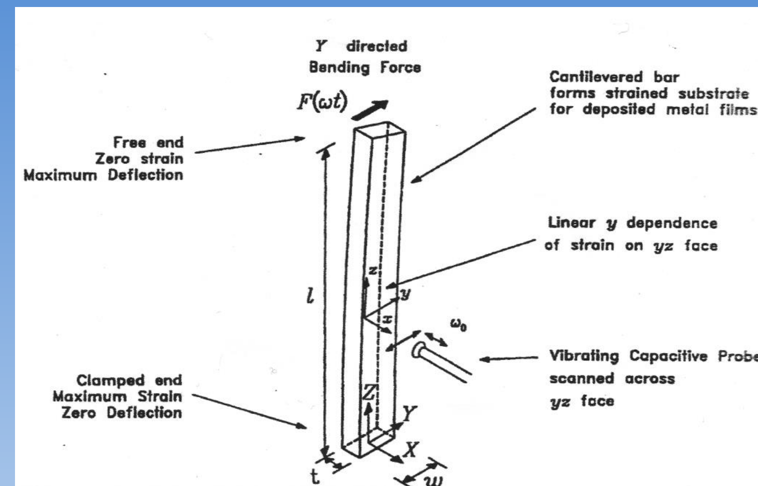
AN OUTSIDE VIEW: UNIVERSITY OF MELBOURNE, GEOFF OPAT and Co-Workers

PhD theses by T.W.Darling and Frank Rossi, University of Melbourne

Studies of Patch Effect and Strain Induced Potentials on Cu and Au Surfaces

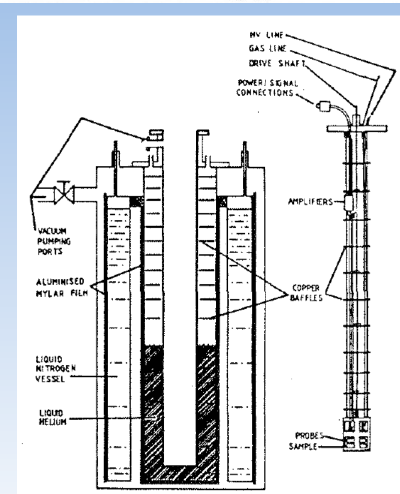
Frank Rossi (1991): Cantilevered Bar with vibrating capacitive probe to study strain induced fields

Surfaces Cu and Au, T 300 K, 10^{-7} Torr
No temperature dependence (WF)
Potential agrees with DMRT
-but opposite sign



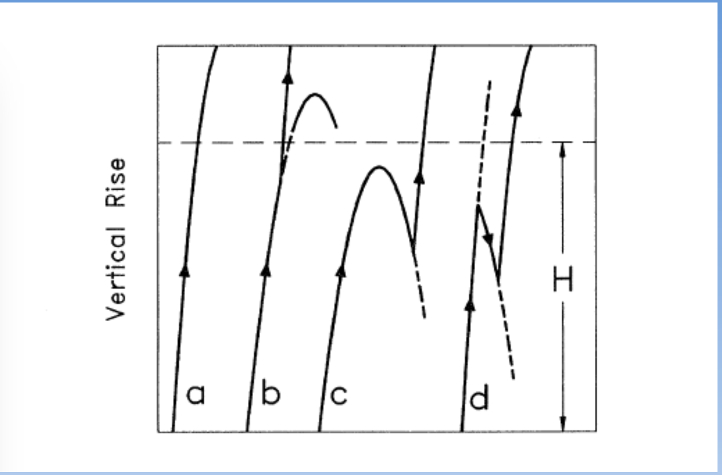
Tim Darling (1989): Moving Capacitor to study patch fields

“designer contaminated” surfaces
T = 4 – 300 K; 10^{-3} to 10^{-6} Torr
No change in patch potential near 4.5 K



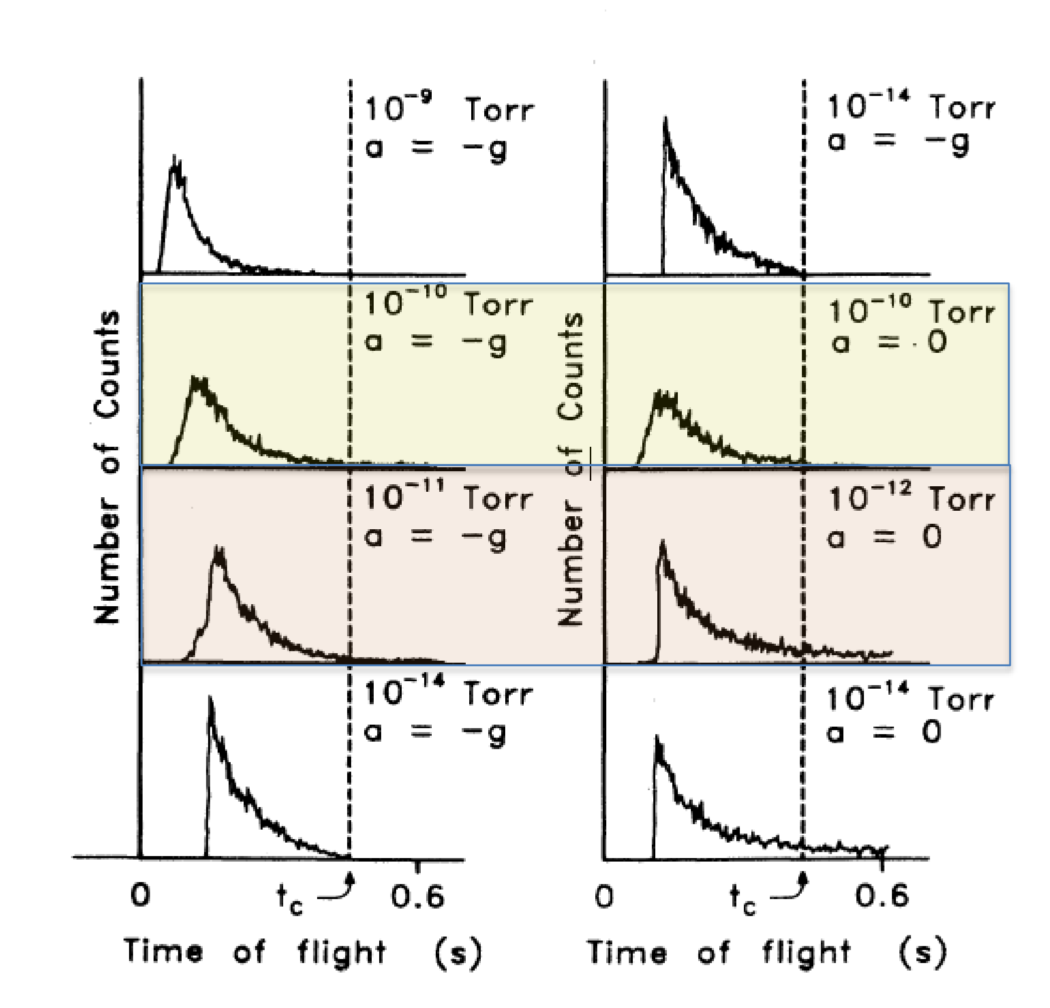
T.W. Darling et al. Rev. Mod. Phys. 64 (1992)

Influence of residual gas

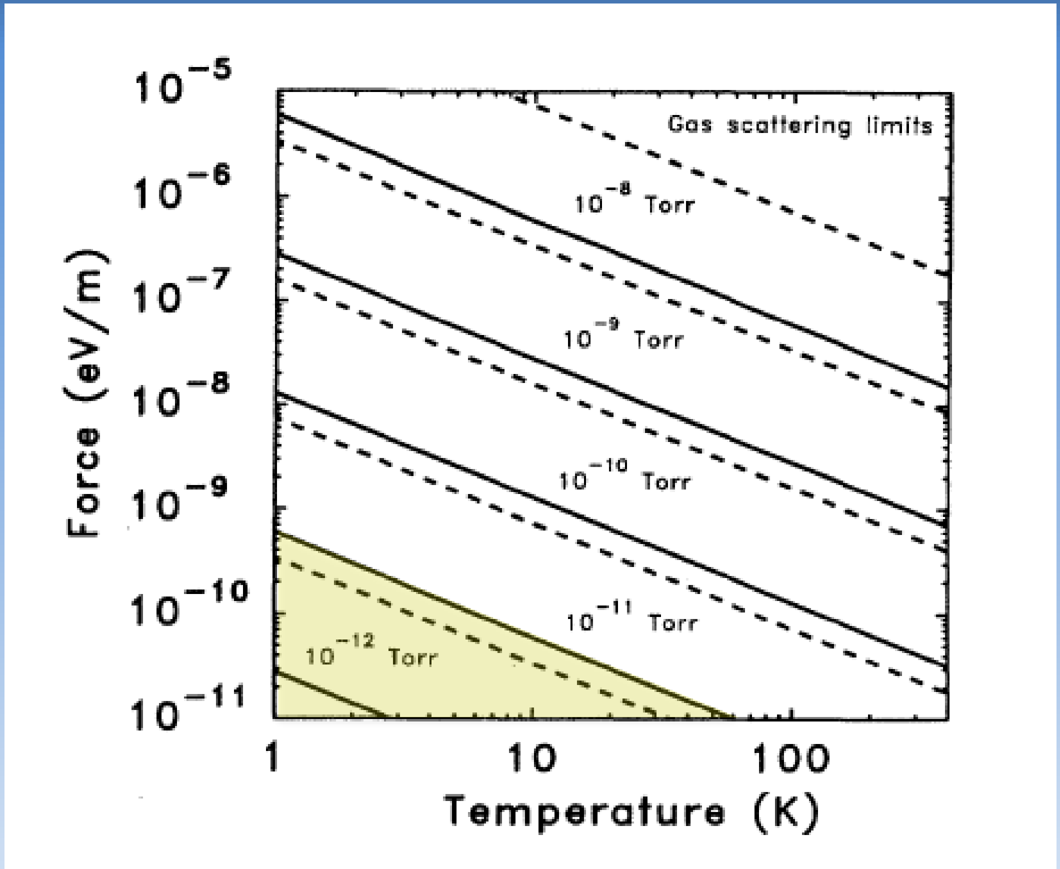


(b) reduces (c) increases TOF!

WF quote p < 10^{-11} Torr
Is this enough???



τ : Collision time; t_c : TOF endpoint → $\tau > t_c$ yields scattering limits



While the temperature-dependent shielding effect claimed by WF may be genuine, it has not been independently verified, despite various attempts.

Measurements by LWF may well have been affected due to cryo-pumping near 4.2 K.

Work function changes near 4.2 K may also exist.

AGAIN and AGAIN: This is an unsolved experimental problem!!!!

Last Words: – Shielding of the Patch Effect – is it understood???

Shielding by electron surface states:

Hanni & Madey; Phys. Rev. B17 (1978) pp. 1976 - 1983

Electron states on surface obeying Fermi or Bose statistics

John Bardeen; in *Near Zero – New Frontiers in Physics* (1987) pp. 874 – 880

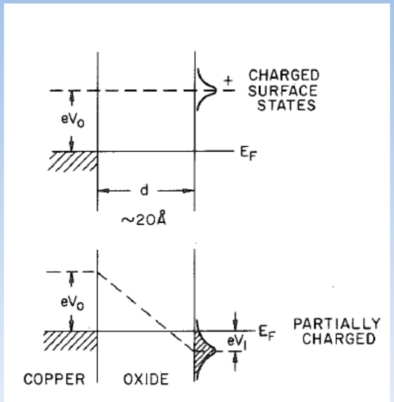
Electron surface states in normal sites on the outermost layer of the oxide

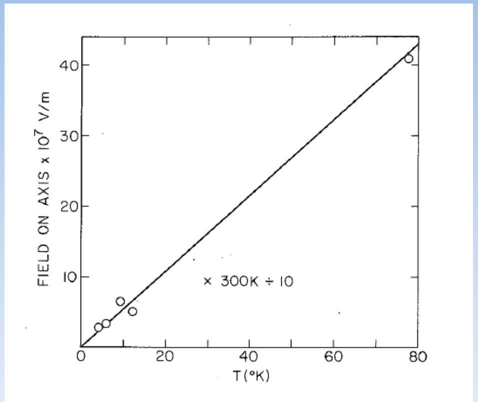
When occupied => normal charge to present a neutral surface

When unoccupied (hole) => positively charged

T > 4.2 K : states are discreet and individually occupied

T = 4.2 K: **Phase transition to metallic state: Narrow band partially occupied by holes => positive surface charge and a 2-D conducting layer on top of oxide.**





Model predicts changes in patch field ≈ T ✓

Surface layer conducting at low temperature increases drop of field with distance ✓

…model suggestive …..hoped future experiments will elucidate remarkable shielding

Gravity Probe B????

Review of Scientific Instruments 82 (2011) 074502

The Experiment:
4 electrostatically suspended cryogenic gyroscope to measure precession of frame
p = 7×10^{-12} Torr; T = 1.8 K

$\Rightarrow$ Observed substantially higher disturbance drifts

$\Rightarrow$ Possible explanation using **100 mV patch effect** on gyro rotor and housing

Success of patch effect model to explain a wide variety of observed phenomena adds credibility to the use of a patch effect model for misalignment and roll-polhode torques in GB-P data analysis.

Differences in materials:
Rotors: fused silica with two layers of 32 patches of niobium sputtered on symmetrically
Housing: fused silica, one half with 4-turn niobium loop, other half with spin-up channel

Assuming 100 mV patches on gyroscopes can explain anomalous signals in data ✓
<u>But:</u> Can anomalous signal on data specify details on patch effect and shielding ???
……..with all respect to Francis Everitt – this is still an unanswered open question!!!

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Fred Carl Witteborn, Stanford University (1965)

James Marcus Lockhart, Stanford University (1976)

John Robert Henderson, Stanford University (1987)

Timothy William Darling, Univ. of Melbourn (1989)

Frank Rossi , University of Melbourn (1991)

SUMMARY:

F.C. Witteborn and W.M. Fairbank observe an effective force on electrons inside metal (drift-) tube to be 0.09 g ≈ 0

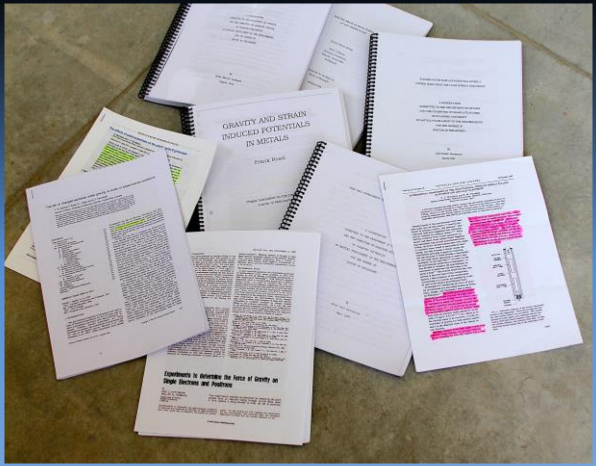
Contradiction to theoretical expectations of effects due to ionic lattice compression (DMRT) and patch effect. But in agreement with sag of free electron gas (SB).

Follow-up experiment by J.M. Lockhart et al. show strong reduction of DMRT and Patch Effect at 4.2 K – but experiments were hampered by technical issues.

No successful models exist to describe and quantify effects.

Numerous experiments using different techniques and set-ups agree with DMRT and/or Patch and did not observe shielding

IMHO THIS REMAINS AN UNSOLVED PROBLEM WARRANTING EXPERIMENTAL ATTENTON



I’ve studied now Electricity
and Surface Physics, Magnetism,
—And even, alas! Quantum Physics,
—From end to end, with labor keen;
And here, poor fool! with all my lore
I stand, no wiser than before

J .W. Goethe (1749-1832)

Thank you for your attention

…and a small consolation to those interested in "anti-gravity" ….

…..it has been explained by, and is available at low cost, at stores all over the USA