

letters

principles are disregarded. And who is to be held responsible for the present situation? Those who created the problem? Or those who are the victims?

BENJAMIN LEVICH
Institute of Electrochemistry
Moscow

The letter above was dictated by telephone to D. B. Spalding of Imperial College, London, and transmitted to PHYSICS TODAY by Spalding at Levich's request.

Theories of gravitation

The article by Clifford Will (October 1972, page 23) gives a timely and interesting account of the separation of viable and nonviable theories of gravitation. However, in a parenthetical statement, which I assume referred to the recent around-the-world flying-clock experiments of Richard Keating and myself, Will states: "Cesium-beam clocks flown recently on commercial jets detected only the time dilation in relative motion—a special-relativity effect; the gravitational red-shift effect was at the limit of their precision." This statement is incorrect, and I would like to set the record straight for those readers who have not read our reports.¹

with their corresponding standard deviations. It can be seen that the measured mean for the westward trip agreed with the predicted value to within about 0.7%, and that the standard deviation (or precision of the measurement) is about 3% of the mean. In fact, the greatest uncertainties reside in the predicted values, whose error estimates were two to three times the precision in the measured values. Clearly the measurements contained both the red-shift and dilatation effects in comparable proportions, with neither at the limits of our precision.

In this context it is interesting to note that these experiments provided more than an empirical resolution of the "clock paradox" of special relativity; they also resolved an issue on the behavior of photons in a gravitational field. The red shift is often described as being due to a loss of energy (and frequency) of the photon as it climbs out of the gravitational field. Another less common explanation, but actually the one Einstein suggested, is that the clocks (or atoms or nuclei) have different frequencies at different gravitational potentials. E. T. Jaynes has argued that without an experimental distinction this issue involves only the meaning of words, and is not a question of physics.² Møller, on the other hand, claims that we should regard the frequency of the photon as being con-

Time gains for round-the-world flying clocks

	Time gains (nanoseconds)	
	Eastward	Westward
Red shift	144 ± 14	179 ± 18
Kinematic Dilatation	-184 ± 18	96 ± 10
Predicted	-40 ± 23	275 ± 21
Observed mean	-59 ± 10	273 ± 7

The Table lists values (in nanoseconds) from our reports for the gravitational red-shift effect, the kinematic dilatation effect, and their sums, which give the predicted relativistic time gains for the flying clocks. It can be seen that the red-shift produced a positive time gain for both circumnavigations, while the kinematic effect had opposite signs—a result that is primarily due to the rotational motion of the earth. Because the red-shift and dilatation effects were comparable in absolute magnitude, near cancellation occurred for the eastward trip where the kinematic contribution was negative, but a relatively large positive time gain was predicted for the westward trip. In this case, the red shift represented about 65% of the predicted value.

Also listed in the Table are the means of the four measured time gains

stant along its path of motion, with the red shift arising from a difference in the frequencies (or energy levels) of the atoms at different potentials.³ Our flying-clock experiments have proved conclusively that the atoms that regulated the clocks had different frequencies at different altitudes.

References

1. J. C. Hafele, R. E. Keating, *Science* 177, 166, 168 (1972).
2. E. T. Jaynes, *Am. J. Phys.* 26, 197 (1958).
3. C. Møller, *Nuovo Cimento Suppl.* 6, 381 (1957).

J. C. HAFELE
Caterpillar Tractor Co
Peoria, Illinois

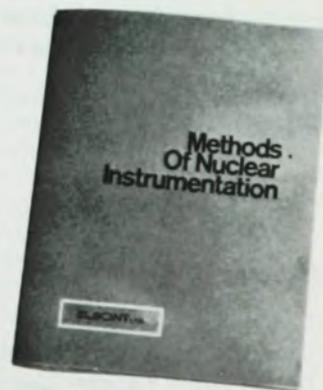
THE AUTHOR COMMENTS: I would like to apologize for having given the wrong impression of the Hafele-Keating

Elscint's Remarkable Timing Discriminator

- VIRTUALLY INDEPENDENT OF RISE TIME
- ±1.4 NANOSECOND WALK IN 100:1 DYNAMIC RANGE, Ge(Li)



Now, walk-free signals using any kind of detector — without amplifiers or timing filters! And if you need even less walk, call ELSCINT... we have the technique. That's typical of ELSCINT's unrivaled line of nuclear instruments.



FREE 16-PAGE
"METHODS
OF NUCLEAR
INSTRUMENTATION"

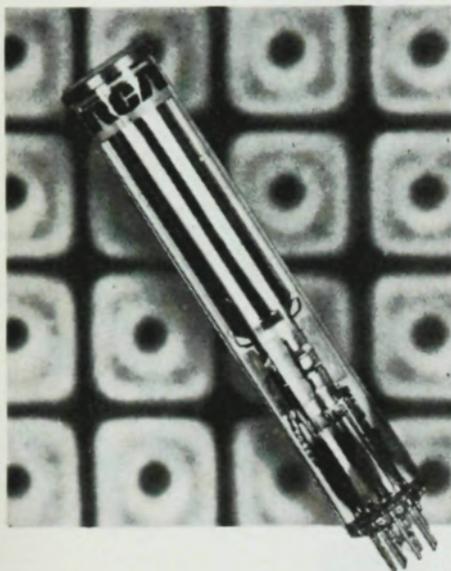
ELSCINT LTD.

Exclusive USA Sales & Service:
PRINCETON APPLIED RESEARCH CORP.
NUCLEAR INSTRUMENT DEPT.
P. O. Box 2565
Princeton, New Jersey 08540
Phone: (609) 452-2111

Circle No. 9 on Reader Service Card

RCA Electro Optics...

Supported by product depth and authoritative data

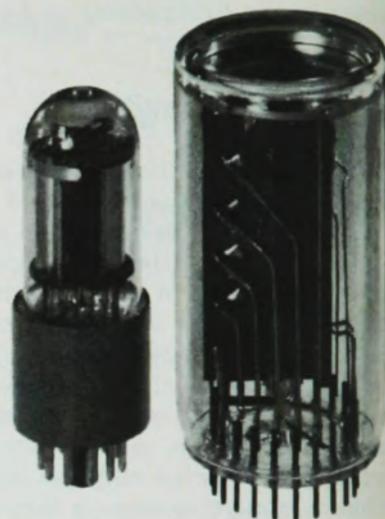


Camera Tubes

Vidicons • Silicon-Target Vidicons • Vistacons • SpectraPlex • Intensifier Vidicons • Silicon-Intensifier Target (SIT) Tubes • Intensifier SIT Tubes • Image Isocons • Intensifier Isocons • Image Orthicons.

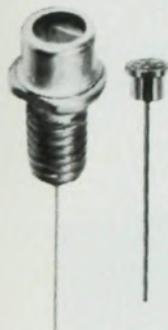
Phototubes

Photomultiplier Tubes (Circular-Cage, In-Line, and Venetian-Blind Types) • Photodiodes (Gas and Vacuum Types) • Electron Multipliers.



Display Tubes

Instrument Cathode Ray Tubes (CRT) • Ultra-high Resolution CRT's • Flying Spot Scanner CRT's • Recording CRT's • Voltage Penetration CRT's • Cathodochromic CRT's • Projection Kinescopes • Display Storage Tubes • Silicon Target and Electrical Storage Tubes.



Solid State Electro Optics

Single-diode Lasers • Laser Arrays • Laser Stacks • Cryogenic Laser Arrays • Solid State Infrared Emitting Diodes • Silicon Photodetectors.

Image Tubes

Image Converters • Electrostatic Focus Types • Demagnifying and Zoom Image Tubes • Light-Shutter Image Tubes • 1-, 2-, and 3-stage Magnetic Focus Types • Image-Stabilization Types • Large-area Intensifier Types • Microchannel Plate Types.



Mgr., Marketing, Electro Optics Products
RCA Electronic Components
New Holland Avenue
Lancaster, Pa. 17604

119C

Please send me the following literature on your Electro Optics products.

- | | |
|---|--|
| <input type="checkbox"/> CAM-703, RCA Camera Tube Product Guide | <input type="checkbox"/> STC-900C, RCA Display Tubes |
| <input type="checkbox"/> CAM-800A, RCA Image Orthicon Product Guide | <input type="checkbox"/> OPT-100B, Infrared Emitting Diodes, Injection Lasers and Silicon Photodetectors |
| <input type="checkbox"/> PIT-700B, Photomultiplier Tubes, Photodiodes, Electron Multipliers | <input type="checkbox"/> PIT-702C, Image Intensifiers and Image Converter Tubes |

Name _____ Title _____

Company Name _____

Street Address _____

City _____ State _____ Zip _____

RCA Electro Optics

letters

around-the-world flying-clock experiment. The cesium-beam clocks indeed detected the gravitational red-shift effect, along with the kinematical time dilatation of special relativity. However, as a high-precision test of the gravitational redshift, it does not compare with the more accurate Pound-Rebka-Snider experiment (1% test), or the proposed rocket redshift experiment (10⁻³% test). Instead, the importance of this experiment lies in its use of macroscopic clocks rather than gamma rays or elementary particles to verify these effects.

CLIFFORD M. WILL
University of Chicago

I should like to add a few comments to Will's very interesting article. These are concerned primarily with the theory of gravitation that the author considers to be "on the firing line," Einstein's meaning of general-relativity theory, and the author's discussion of "Test-2."

Firstly, Einstein clearly emphasized that his theory of general relativity is not restricted to a theory of gravity, and that the latter development from the theory was only a consequence of the solutions of a formalism that was "a makeshift to give the general principle of relativity a preliminary closed expression."¹ The theory itself (rather than its mathematical expression) is a hypothesis about the laws of nature, expressed in terms of this principle, that is, the assertion that the laws of nature (of any type!) must be objective with respect to reference frames that are distinguished by arbitrary types of relative motion in space-time.

From Einstein's own point of view, then, the "meshing" of his law of gravity with the other laws of physics is logically necessitated by the axiomatic basis of his theory. Indeed, this was the primary motivation for his pursuit (during 40 years or so of his career) toward a unified field theory. That is, it was not simply for the aesthetic pleasure that might be gained in unifying electromagnetism with gravity. Einstein anticipated that such a unification would lead to the further incorporation of the fundamental features of matter in the microscopic domain.

Thus, an important test of general-relativity theory that Will did not emphasize is its implications in the microscopic domain of elementary-particle physics. This is not to say that the gravitational force, *per se*, is important in this domain. But according to general-relativity theory, the "inside of an

elementary particle" must necessarily be characterized by a highly curved space-time, which in turn would have profound effects on many of its physical properties. A recent review summarizes work in this area.² One of the important results, which is sensitive to the curvature of space-time in the microscopic domain, is the prediction of an explicit field relation between the inertial mass of an "elementary particle" and the geometry of space-time, as determined by all of the remaining matter of a closed system—the full incorporation of the Mach principle in general-relativity theory. A recently reported application of this result led to the inertial masses of the electron and the muon, predicted as a mass doublet, in terms of the curvature properties of space-time,³ and the lifetime of the muon state of this doublet.⁴ These theoretical results are then claimed to be successful tests of general relativity (as the theory is defined by Einstein) applied to the elementary-particle (rather than the astronomical) domain. The necessary incorporation of all domains of interaction in this theory was discussed in an earlier article in *PHYSICS TODAY*.⁵

It has also followed from this research that Will's distinction between Einstein's theory and the scalar-tensor theory of Dicke-Brans-Jordan is not as clearcut as he indicates. According to the principle of general relativity, the most general explicit form of the invariant differential metric is not in terms of its square, $ds^2 + g_{\alpha\beta} dx^\alpha dx^\beta$, as expressed by Will. In accordance with the symmetry group of this theory (the 16-parameter Lie group that underlies the invariance of ds) the space-time metric field must entail the solutions of 16 field equations at each space-time point, rather than ten.⁶ Because the irreducible representation of this group obeys the rules of a quaternion algebra, I have started with the quaternion invariant metric $q_\alpha dx^\alpha$, where q_α is a four-vector field, and each vector component is, algebraically, a quaternion rather than a real number. I have derived the field equations in q_α and find that in an iterated form, ten of these equations are in one-to-one correspondence with Einstein's symmetric tensor equations, thus predicting all of the physics that is predicted by the tensor formalism. But there are six more field equations—thus the formalism predicts more. In particular, it was found that in a linear approximation, where $v/c \ll 1$ (as in the case of Mercury's motion relative to the sun) the six remaining field equations reduce to one important equation—which solves the scalar field equation—and five other equations that are unimportant in the first approximation. In this limit, then, the formal structure of this theory is iden-

Tubes? Forget them.

HERE'S 100 WATTS OF SOLID-STATE RF POWER!



A state-of-the-art amplifier.

ENI's new Model 3100L all-solid-state power amplifier provides more than 100 watts of linear power and up to 180 watts of pulse power from 250 kHz to 105 MHz. This state-of-the-art class A unit supplies over 50 watts at frequencies up to 120 MHz and down to 120 kHz. All this capability is packaged in a case as small as an oscilloscope, and it's just as portable.

Extraordinary performance.

Featuring a flat 50 dB gain, the Model 3100L is driven to full power by any signal generator, synthesizer or sweeper. AM, FM, SSB, TV and pulse modulations are faithfully reproduced by the highly linear output circuitry. Immune to damage due to load mismatch or overdrive, the 3100L delivers constant forward power to loads ranging from an open to a short circuit.

Solid-state reliability is here.

The price? \$5,690.

Write for complete information: ENI, 3000 Winton Road South, Rochester, N. Y. 14623
Call (716)-473-6900 or TELEX 97-8283

**ELECTRONIC
NAVIGATION
INDUSTRIES**

ENI . . . The world's leader
in solid-state power amplifiers.

Circle No. 11 on Reader Service Card

WHAT'S
COLD
DOING IN
FLORIDA?



The University of Florida at Gainesville is one of a growing number of universities and research centers that have opted for an in-house capability to produce liquid helium.

Florida's Department of Physics and Astronomy, for example, has extensive research projects both in solid-state and in low-temperature physics, some involving high-field superconducting solenoids, requiring steady supplies of the "lifeblood" fluid of low-temperature research.

These projects include NMR and NQR studies of phase transformations, lattice dynamics, and

structure of solids; thermal expansion and isothermal compressibility of solids at low temperatures and high pressures; nuclear spin ordering in solid ^3He in high magnetic fields and in zero fields; ultralow-temperature properties of liquid ^3He ; mixtures of ^3He and ^4He ; dispersion curve of liquid ^4He ; ion mobility in superfluid helium films; and creation process, structure, and dynamics of quantized vortex excitations in superfluid helium.

A reliable supply of liquid helium for these and other programs at Florida is provided by a CTi Model 1400 Helium Liquefier.

The Model 1400 was designed both for the laboratory requiring a

regular supply of liquid helium and for the research center needing a continuous source of cold for, say, superconducting devices and systems. The Model 1400 can be operated periodically, or it will run for months at a time between routine maintenance periods. It can produce from 5 to 40 liters per hour of liquid helium; 20 to 100 watts of refrigeration at 4.5°K; 100 to 300 watts of cooling at 20°K, and can be modified for hydrogen or neon liquefaction.

Write or call CTi today for full details on the versatile and reliable Model 1400 Helium Liquefaction/Refrigeration Systems.

The growing Company that makes COLD as simple as heat.

CTi CRYOGENIC TECHNOLOGY, inc.

Kelvin Park, Waltham, Massachusetts 02154 (617) 890-9400

letters

tical with a truly "scalar-tensor theory," but only as approximation to a formalism that is the most general (that is, irreducible) expression of Einstein's general-relativity theory.⁷

Finally, I do not believe it is strictly true within Einstein's theory that "in local reference frames all non-gravitational laws of physics take on their standard special relativity forms." For, if space-time is curved anywhere, it must be curved everywhere, in accordance with the transformation properties of such a space-time. Thus the field variables associated with laws other than gravity are still mapped in a curved space-time—even though in special "local" applications they can be approximated by fields mapped in flat space-times that are the tangent planes to the points of observation in the actual curved space-time. Such a difference in the exact fields of the non-gravitational law does indeed influence their structures; for example, ordinary derivatives become covariant derivatives, thus necessitating the addition of certain non-zero geometrical field variables in the field equations. That is to say, the predictions of an exactly flat space geometry (with special relativity) and those of the curved space geometry (general relativity) are not precisely the same, even in the "local limit."⁵ It is my belief that in the coming decades these differences may become detectable, not only in astronomical experimentation, but also (and perhaps more sensitively) in high-energy physics experimentation.

References

1. A. Einstein: "Autobiographical Notes" in *Albert Einstein: Philosopher-Scientist* (P. A. Schilpp, ed.) Lib. Liv. Phil. (1949).
2. M. Sachs, *Int. Jour. Theoret. Phys.* 4, 433, 453 (1971); 5, 35, 161 (1972).
3. M. Sachs, *Nuovo Cimento* 7B, 247 (1972).
4. M. Sachs, *Nuovo Cimento* 10B, 339 (1972).
5. M. Sachs, *PHYSICS TODAY*, 22, 51 (1969).
6. M. Sachs, *Nature*, 226, 138 (1970).
7. M. Sachs, *Nuovo Cimento* 47, 759 (1967); 55B, 199 (1968).

MENDEL SACHS

State University of New York at Buffalo

We should all be thankful to Clifford Will for his concise and informative article concerning the present state of theory and experiment in gravitation. It is interesting to see that gravity, after a long lull, has become alive again, with exciting prospects of experimental inquiry and theoretical construction. This letter is intended to

clarify the issue of viability of our 1971 theory.¹ Although quite unconventional in its philosophical setting, this theory is found viable under several physical interpretations of its equations. Two extreme positions that one could take and still have the theory viable are:

(a) Consider the theory as a direct generalization of special relativity, where Einstein's second postulate is extended into noninertial frames by the statement: "As measured in a sufficiently small laboratory the signal velocity is a universal constant, independent of any field of acceleration that may be present in that laboratory." Here the "signal velocity" means the velocity of massless fields including gravity, and the universality is to be maintained despite the presence of gravitational fields and their first derivatives. The statement implies that the metric structure of special relativity is being taken over into noninertial frames in the local sense above, although the geometry is, in general, curved. If accelerations vanish everywhere, the theory becomes globally special relativistic in the sense that the laboratory can be as large as desired. This implies that in the process of parallel transport the absolute values of the fields are unobservable, hence only the differences, $\phi_{\alpha\beta}(x) \rightarrow \phi_{\alpha\beta}(x) - \phi_{\alpha\beta}(x')$, where x' is the position of the observer, are relevant.² To make the signal velocity independent of the gravitational accelerations we require the d'Alembertian be independent of the derivatives of $\phi_{\alpha\beta}(x)$. This implies³ that $dg_{\eta\mu} = A(g_{\mu\nu}d\phi - g_{\mu\lambda}d\phi_{\nu}^{\lambda} - d\phi_{\mu}^{\lambda}g_{\lambda\nu})$, $\partial_{\nu}\phi_{\mu}^{\nu} = 0$. Then the principle of equivalence yields $A = 2$; hence the local equations of $g_{\mu\nu}$ are determined. These equations are equivalent to some field equations that can be derived by simply calculating the Ricci tensor. One finds $R_{\mu}^{\nu} - (1/2)\delta_{\mu}^{\nu}R = 8\pi(\sigma_{\mu\nu}u^{\nu} + t_{\mu}^{\nu}/4\pi)$, where $\square^2\phi_{\mu}^{\nu} = 4\pi\sigma_{\mu\nu}u^{\nu}$ and t_{μ}^{ν} is the canonical stress-energy tensor, corresponding to the field Lagrangian, $L_{\Gamma} = -\partial^{\lambda}\phi_{\alpha\beta}\partial_{\lambda}\phi_{\beta}^{\alpha} + (1/2)\partial^{\lambda}\phi\partial_{\lambda}\phi$. Thus the theory is a locally Lorentz invariant field theory of gravity where the gravitational part t_{μ}^{ν} contributes to the geometric curvatures. Since $g_{\mu\lambda}g^{\lambda\nu} = \delta_{\mu}^{\nu}$, the equations can be iterated into the (matrix) form, $\bar{g} = \bar{\eta} \cdot \exp 2(\phi - 2\bar{\phi})$, where $\bar{\phi}$ is the field matrix $\phi_{\mu\nu}$, ϕ is the diagonal matrix $\bar{1} \cdot \text{trace } \phi$, and $\bar{\eta}$ is $\phi_{\mu\nu}$. Although this solution is exact everywhere in the local sense above, it must be regarded as an ordered integral for finite differences $\phi_{\alpha\beta}(x) - \phi_{\alpha\beta}(x')$ due to possible noncommutativity of finite contributions. It is, however, found that in the first and second order there is no problem even for finite differences. Ex-

continued on page 55

FIELD PROVEN . . .

HIGH VOLTAGE TRIGGERS



Size: 5-3/4" x 4" x 2-1/4"

Outstanding features of TOBE DEUTSCHMANN TG's include:

- Fast rise time ~5 nanosec.
- Extremely low jitter . . . ~3 nanosec.
- High amplitude. .50kV pulse output.
- Pulse repetition frequency ..1 pps.

All TG series triggers provide a high energy fast rise pulse for reliable firing of capacitor discharge switches and systems. Triggers may be parallel or sequentially fired with minimum inter-pulse jitter.

Designed to improve the performance of high voltage spark gap switches, TG's also eliminate the need for elaborate triggering circuitry. Both positive and negative output models are available. Triggers are extremely compact and hermetically sealed for long life.

For further information on TG's and high voltage capacitors/systems, write or call:

Tel: (617) 828-3366
Telex: 92-4427



CANTON, MASSACHUSETTS 02021

Circle No. 13 on Reader Service Card

letters

continued from page 15

panding in first and second order, and noting that in the weak and quasistatic limit (which is the case for all the experiments discussed by Will) two of the terms cancel; one has $g_{\mu\nu} = \delta_{\mu\nu} (1 + 2\phi + 2\phi^2) - 4\phi_{\mu\nu}$. This corresponds to $\beta = \gamma = 1$, $\alpha_1 = \alpha_2 = \alpha_3 = 0$; hence the theory's post-Newtonian limit agrees with current experiments. The usage of $\phi_{\alpha\beta}(x) - \phi_{\alpha\beta}(x')$ instead of just $\phi_{\alpha\beta}(x)$ is something new, but this does not cause any serious problem. It is found that the $\phi_{\alpha\beta}(x')$ term might, in fact, be of value in the interpretation of Sagnac-type experiments, where the issue of the local velocity of light has traditionally been quite unsatisfactory.

(b) If the above interpretation, in which the solution is exact but the interpretation is unconventional, is regarded too drastic we can view the theory as given by its field equations and, in a more conventional way, search for a PPN-type solution, $g_{\mu\nu} = \delta_{\mu\nu} (1 + A\phi + B\phi^2) + C\phi_{\mu\nu} + D\phi\phi_{\mu\nu} + E\phi_{\mu\alpha}\phi_{\alpha\nu}$. This is perfectly legitimate and can be done for the Einstein and Dicke-Brans-type theories as well. One finds the coefficients: Einstein (2, 3/2, -4, -7/2, 4); Dicke-Brans (2 - 2/ ω , 3/2, -4 + 2/ ω , -7/2, 4); Present (2, 2, -4, -8, 8). Substituting back into $g_{\mu\nu}$ one finds again that, in the post-Newtonian order, the theory is the same as Einstein's theory, hence viable. Note that in this interpretation the special-relativistic correspondence is achieved in the sense of $g_{\mu\nu} \rightarrow \delta_{\mu\nu}$, $\phi_{\alpha\beta} \rightarrow 0$; hence the iteration solution is not necessarily exact beyond second order, although in the static limit it yields again an exact solution. An interesting feature is that the first-order coefficients A and C determine the second-order ones as $B = A^2/2$, $D = AC$, $E = C^2/2$. A combination of local validity of special relativity and the principle of equivalence further yields $A = -C/2 = 2$, and implies the validity of iteration to fourth order in the quasistatic limit; but these are not important for our present purpose.

The theory differs from Einstein's theory in strong and nonstatic phenomena and therefore requires an extension of the usual PPN formalism, as these phenomena appear to be testable via suitable models of quasars and pulsars.⁴ Here one might contemplate the coefficient of the ϕ^2 term in g_{ij} and that of ϕ^3 in g_{00} as new PPN parameters. Likewise the interpretive difference mentioned above could possibly be parametrized by giving a coefficient to $\phi_{\alpha\beta}(x')$ in the potential difference $\Delta\phi_{\alpha\beta}$. In this connection it is interesting to note that a recent advance⁵ in the measurement of light ($\delta c = \pm 1$

The Best Potential for ... Phototubes ... Photomultipliers ... Ion Sources are KEITHLEY DC High Voltage Supplies



NEW LOW COST MODEL 244 furnishes negative-only potentials from -200 to -2200 volts at up to 10 milliamperes. It operates quietly, with less than 500 microvolts noise and is solidly stable to 50 ppm. Fully overload-protected, with automatic recovery, the 244 also offers a unique photomultiplier protection circuit option—the Model 2441 (price on request). The Model 244 is budget priced at only \$325. Less in quantity.



PERFORMANCE-PROVEN MODEL 240A reliably supplies bipolar voltages from 0 to 1200 volts in 1 volt steps. Rated at 10 milliamperes, the 240A smoothly recovers from no load to full load in 35 milliseconds. Capable of both resistance and voltage programming, the 240A also features full overload protection with automatic recovery within 250 milliseconds.

Stable to 0.02% and steady to 0.005% for both load and line changes. Get all this for just \$385. Less in quantity.



MODEL 246 HIGH VOLTAGE SUPPLY gives a selection of any output of both polarities from 0 to 3100 volts. The 246 is rated at 10 milliamperes and features automatic recovery from overloads within 1 second. Maximum output current is electronically limited to 13 milliamperes. It adapts easily to either voltage or resistance programming. Stable to better than 0.01% with 0.002% load regulation. A perfect buy at \$495. Less in quantity.

OTHER KEITHLEY HIGH VOLTAGE SUPPLIES — PRICES LOWER IN QUANTITY

Model 241 ± 0 to 1000 volts, floating/accurate . . . \$975
Model 245 ± 0 to 2100 volts, stable/bipolar . . . \$450
(U.S.A. Prices)



KEITHLEY INSTRUMENTS

U.S.A.: 28775 AURORA ROAD, CLEVELAND, OHIO 44139 / EUROPE: 14, AVENUE VILLARDIN, 1009 PULLY, SUISSE

Circle No. 26 on Reader Service Card

500 Parallel Optical Channels with 1 OMA*

*SSRI Model 1205 OPTICAL MULTICHANNEL ANALYZER®



**NOW: QUANTUM LIMITED...
INTENSIFIED**

Recently introduced, SSRI's OMA[®] has become a vital tool for numerous spectroscopic applications. Simultaneous integration of the dispersed spectrum into each of 500 parallel optical channels achieves results unattainable before. Proven applications include:

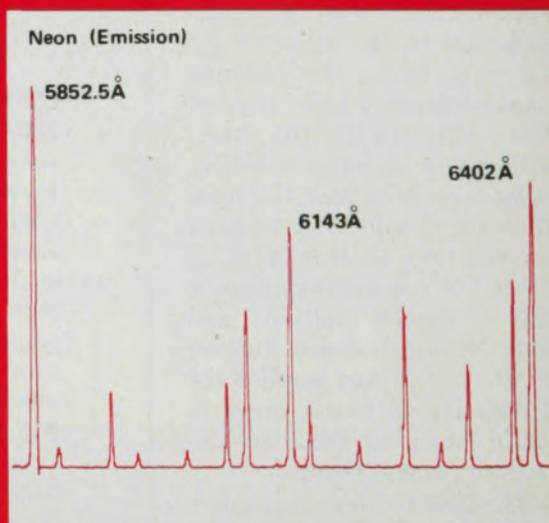
- UV, visible & near, I.R.
- Colorimetry
- Astrophysical
- Flash Lamp Analysis
- IR Absorption
- Laser Diagnostics
- Kinetic Chemistry
- Pulsed Laser
- Raman Spectroscopy
- Emission Spectroscopy

A few of the features with unusual significance to the advanced spectroscopist include:

- High Quantum Efficiency
- Broad Spectral Range
- Digital Signal Averaging
- Background Subtraction
- Scan Beam Chopping

A complete spectrum comparable to the one shown here (Neon Emission) is produced by the OMA in 32 milliseconds with a resolution better than 20 lines/mm on the vidicon target. SSRI's OMA[®] operates in the wavelength region of 200nm to 1100nm.

® Registered Trademark



SSRI INSTRUMENTS CO.
a subsidiary of Princeton Applied Research Corp

1001 Colorado Avenue, Santa Monica, California 90401
(213) 451-8701 Cable: Photon Telex: 65-2466

Call me for appointment Mail literature

My application is _____

Name _____ Title _____

Firm _____

Address _____

City _____ State _____ Zip _____

m/s) seems promising toward a direct test of the local universality of the velocity of light in non-inertial (rotating, artificially accelerated or gravitational) frames of reference.

Finally, if the first interpretation above turns out to be valid, we can see an interesting connection with the so-called Schiff conjecture mentioned by Will. For in this interpretation $g_{\mu\nu}$ is essentially a transformation, $dx_{\mu} = g_{\mu\nu} dx^{\nu}$, between the covariant and contravariant descriptions. As such, $g_{\mu\nu}$ does not have to satisfy the commutability of finite contributions, but metricity (the existence of a nonsingular $g_{\mu\nu}$) is needed to satisfy the requirement of objectivity (equivalence) of the two descriptions. The composition independence of free-fall would then become a corollary, because a metric theory is equivalent to a kinematics where mass does not enter into the consideration of motion. Schiff's idea of a connection with quantum mechanics is then realized in the sense that only in a metric theory will the wave equation and the geodesic equations of motion yield identical results in the limit of geometric optics (for example the bending of light or aberration). Hence the wave-particle duality seems to imply, already in its classical form, the metricity of geometry. The explicit universality of the Planck constant appears, however, not necessary for the argument, although it might be crucial for the quantizability of gravity itself.

The author wishes to thank Clifford Will for his critical reading of this letter and for his suggestions that are incorporated.

References

1. H. Yilmaz, Phys. Rev. Lett. **20**, 1399 (1971).
2. H. Yilmaz, Phys. Rev. **111**, 1417 (1958).
3. H. Yilmaz, Lettere Al Nuovo Cimento (in press).
4. R. E. Clapp, Phys. Rev., **D 7**, 345 (1973).
5. K. M. Evanson and others, Phys. Rev. Lett. **29**, 1346 (1972).

HÜSEYİN YILMAZ

Perception Technology Corporation
Winchester, Massachusetts

Correction

December 1972, page 53. In the review of *Color and Symmetry* by A. L. Loeb, the reviewer's name should be spelled *Donnay*. He is affiliated with Johns Hopkins University and the Université de Montreal. In the fifth line of the center column on page 53 there should be a comma after the word "rotocenters," and the first displayed equation in that column should have a closing parenthesis after the italic *k*. □

Investigate the great detectors



Bendix detectors for:

Mass Spectrometers	28
ESCA	29
Field Ion Microscopes	30
Electron Microscopes	31
UV Photon Spectrometers	32
Electron Spectrometers	33
LEED Spectrometers	34
Other	35

(circle inquiry number)

Bendix electrical detectors (continuous dynode electron multipliers and multiplier arrays) represent a unique new approach. For most every application. We have detectors that do particle counting, analog mode. That detect moderate energy ions, soft X-rays, UV photons, electrons, beta particles, protons.

They come in sensing area diameters from 1 millimeter to over 75 millimeters, with a remarkable degree of compatibility (and we'll gladly work with you on special circumstances). They can be operated at electron gains up to 1×10^7 — and higher — with the loss of very few counts and low noise.

Investigate these great detectors by circling the inquiry number that fits. We'll send you detailed information about a very interesting solution.

(Also ask us about Bendix Fused Glass Capillary Arrays for such things as micro cell filtration and gas particle collimation. Circle number **36**

Contact: The Bendix Corporation
Electro-Optics Division
Galileo Park, Sturbridge, MA 01518
(617) 347-9191

