Born: Oct. 8, 1935, New York City

BA (Mathematics) Harvard College, summa cum laude (1956)

William Lowell Putnam prize in 1956

PhD (Physics) Columbia University 1962 (sponsor T. D. Lee)

Professor of Physics at Bernard College & Department of Physics at Columbia University, (1968-2003)

Book (mathematics, popular): An Adventurer's Guide to Number Theory
(New York, Mc Graw-Hill, 1968; reissued by Dover Publications, Inc. (1994)

Richard Friedberg is a theoretical physicist of exceptional talents and very humble nature. The following quote by David Mermin perhaps sums it all up: " Richard Friedberg is the smartest person I have ever met (and I've met some very smart ones). He is also, an exceptionally decent person...".

Above statement resonates with almost everyone who know Friedberg. He is deeply loved, admired and adored by his colleagues, friends and his students. However, unlike his peers, he is relatively unknown outside a close circle of those who know him. He does not like promoting his work and is happily lost in his own magical world of physics and mathematics.

Oeuvre of Richard Friedberg

Perhaps the best work by Friedberg dates back to mid 1950s when he was an undergraduate at Harvard. Below is a summary, in his own words of his personal favorites among more than 100 papers that he has published. This list shows his breadth of capabilities to plunge into any thing with his mathematical wand.

" *In Recursion Theory I published some 8-9 papers over a period of 2 -3 years[1–4]. The first, Two Recursively Enumerable Sets [1]introduced a trick called the priority method, which became a fundamental technique in the subject. The paper Three Theorems[4] could have been three papers, but they went together well because of a common form of presentation. I like especially the third theorem, Enumeration without Duplication. Constructing it felt like writing a symphony because of the weaving together of different techniques (including priority) used in different parts of the construction.*

Some of my personal favorites are in mathematical methods – my solo papers are closest to my heart: the Dual Tree paper[5], the Conducting Disc paper[6], and the Path Integral paper[7].

" In solid state physics, I'll pick out Ann. Phys. **208***[8] as being most significant and owing a major part to my contribution."*

In lattice physics, Ann. Phys. **228** *[9] was an exhaustive treatment of a minor problem (The Eden model turned out to be relatively uninteresting) but my methods considerably outpaced what had been done before on this model. J. Phys. A20 52 is more dear to me - it showed how certain lattice quantities could be calculated with incredible speed.*

In general relativity, Nucl. Phys. B **242***[10] is really about a lattice version of Einstein's theory. Regge had proposed this lattice version as a sort of analogy which would presumably reduce to Einsteins theory for a very fine lattice. T. D. Lee and I started out studying how good an approximation it was. In the course of this we interpreted the lattice model as a kind of restricted continuum model, and I noticed that in every simple case I tried, the application of Einsteins formulas to this continuum model was in exact agreement (even for a finitely spaced lattice) with Regges formulas. But I was unable to prove that this would be true in all cases. T. D. rolled up his sleeves and arrived at a full proof.*

Quantum Optics *The papers with Hartmann and Manassah cover three periods: early (1971-1974), middle (1988-1993) and late (2008-2012). Broadly, they all involve the interaction of resonant or near-resonant light with atomic matter. In the early period there were many more papers than the three shown. Phys. Letters* **37** *A [11] was important as it showed that a certain situation was quite different from the way it had been pictured. Phys. Reports 7C, 101 [12] was exhaustive and somewhat monumental, and treated many different approaches to the subject of frequency shifts with a consistent effort to display them in relation to one another. I like Opt. Comm. 10 298[13], it is cute and surprising. In the middle period the most important was probably J. Phys. B* **21***[14] but it owed much more to Hartmanns vision than to mine. In the late period, although it all grew out of work with Manassah, the papers most dear to me are some I did alone, including Ann. Phys.* **325** *[15] and J.Phys. B* **44** *[16].*

Genome Research *Of the papers on genome rearrangement, the most significant is surely the first one, Bioinformatics* **21***, (2005)[17]. It introduced a fictitious operation DCJ (double cut and join), jointly conceived with S. Yancopoulos, which soon aroused considerable interest among mathematicians studying the subject, though not so much among practical investigators.* ".

In 1968, Friedberg proved independently what became known as Bell's inequality, not knowing that J. S. Bell had proved it a few years earlier. He showed it to the physicist and historian Max Jammer, then visiting NYC, who somehow managed to insert it into his book "The Conceptual Development of Quantum Mechanics", New York, McGraw-Hill although the latter bears the publication date 1966. This caused Friedberg some embarrassment later when classmates at Harvard, knowing of the result only through Jammer's book, supposed that Friedberg was the first discoverer.

(A letter from Friedberg to Jammer dated May 1971 begins, "It was nice of you to remember what I showed you in 1968. I finally got around to writing it up in 1969, but just then I found out about Bell's 1964 paper (Physics 1, 195) which had anticipated my 'discovery' by three years. So I did not publish.")

For last couple of years, Friedberg and Hohenberg (who passed away on Dec 15, 2017) collaborated on Foundations of Quantum Mechanics[18].

Friedberg was born in Manhattan on Oct 8, 1935. His father, Charles K. Friedberg, was a renowned cardiologist whose book "Diseases of the Heart", published by W B SAUNDERS

(1949, 1956, 1966), was translated into many languages and became the undisputed ”bible” for its thorough explication of physiologic mechanisms combined with its straightforward clinical advice to physicians, drawn from the author's own practice. His mother, Gertrude Tonkonogy, wrote a play, “Three-Cornered Moon”, whose success on Broadway in 1933 was felt to have “rescued” a season in which the theatrical world was uncertain whether any play would draw audiences in the depth of the Great Depression.

Ode to Richard

Friedberg is loved and adored by his colleagues, friends and students. The following words from his students convey the sense of blessings and appreciation they feel for the opportunity to work with him.

“*The time I spent with Richard during my Ph.D. and later during one of my sabbaticals at Columbia has been the most memorable period of my scientific carrier and has left lasting impressions on the way I do science. I have come to know Richard not only as a physics mentor but also as a guru who taught me how to be a good scientist. I have never met anyone who can quickly manipulate large numbers in his mind as he can. The most important lesson that I learned was to look at a problem from many different angles and find as many different solutions to ensure that they are all consistent to be sure of the conclusion. There is a price you must pay occasionally in that you are scooped by others before you can publish your conclusion. Besides being a guru, Richard has been one of the easiest persons to get along with. His gentle nature, his vast range of interests besides theoretical physics, and his passion for piano playing at a high level makes him a unique scientist although he also had his share of a turbulent life while I was his student. He eventually came out of it but it was rough for a while. It is a privilege to write a few words for this great guru of mine.* ”

“*I consider myself lucky to have had Richard as my doctoral guide .My first exposure to his incredible talent and confidence was that he allowed me to choose a thesis problem in a field he was not actively involved. His mild nature always seemed to guide me towards a do it yourself solution; even in our discussions during this period we spoke about a wide variety of subjects not related to my thesis work on liquid helium, it could be from Ramanujans partitioning of integers to soliton solutions. After my doctorate, I returned to India and was not actively involved in*

physics and got more involved in engineering and textiles. During my visits to Columbia he was happy to see the kind of solutions I was generating for the industry. I continued to do physics more as a hobby; this gave me time to think freely instead of giving into pressures of publication. Whenever I used to visit Columbia he was always receptive to my ideas, never threw them away as impractical or even suggested that it would not lead me to any new insights to the problem at hand. I believe that he was and is the inspiration that keeps me going as I meander through cosmology and phase transitions and whatever takes my fancy. His mild personality amply came out when visa of one of his doctoral students was blocked by the U.S consulate in New Delhi. After a few days mental turmoil he admitted that he really had to work himself up to be aggressive and call the consul General and tell him in no uncertain terms that the visa was imperative to work being done at Columbia by his student. Needless to say the visa was granted. During my batch of doctoral students, we had an expression among ourselves to pull a Friedberg meaning suddenly , apparently from nowhere he would come up with a concept /trick to make the problem tractable. The lists of his publications show that he worked on a vast canvas of physical and mathematical problems contributing significant insights and techniques applied to wide array of problems. This is the essence of Richard .

"*Richard Friedberg has the gift of a nearly magical mathematical intuition, and his extraordinary visual way of approaching abstract concepts is a gift I got from him. It made theoretical physics so much fun and joyful. This style has stayed with me ever since my student days, becoming part of me, and in my own teaching I continue to strive to pass it on to my students. One of the most important things that my work with Richard cultivated in me was to be absolutely in love with what I do, and to remain almost immune to the highly competitive culture that pervades the scientific community today.*"

Poems by Richard Friedberg

As one digs little deeper, the polychromatic personality of Friedberg that many may not know emerges. Those close to him know his love for music. He is a gifted pianist. His popular-level book on Number theory – *An Adventurers Guide to Number Theory (New York, Mc Graw-Hill, 1968; reissued by Dover Publications, Inc. (1994)* radiates the beauty and the poetry he finds in mathematics. He writes in the book – "The difference between the theory of numbers and

arithmetic is like the difference between poetry and grammar".

Two poems below[19], give us a sense of poetic part of him. Of these poems, he says, "*It seems to me that poets since P. B. Shelley (my mentor here) who have tried to stay abreast of science mostly just stick scientific terms into their verse that have no emotional content for them, and the effect is only to show how alienated they are from what they think they are talking about. I have in mind particularly T. S. Eliot - I could give many examples. Also J. H. Updike's poem starting 'Neutrinos, they are very small', deservedly beloved among physicists and others, does not really move toward the scientific facts as much as away from them, ending with a rebuke to these particles as though they were people. My two poems stick strictly to scientific facts, attempting to show that those facts* themselves *are poetical.* "

The Electromagnetic Spectrum

Neither the long slow rolling of the ether
That wakens metal to its fiery dance
Nor the chaotic bustle warmth sends hither,
Pricking our stuff with catapults of chance,

Nor yet those rays that strike us at the bone
And fit their steps to crystal's even stair
Nor Nature's hardest bits, that break and shower
Already at the kiss of thinnest air,

So vivid gleam, put on such various hue
Touch so the three-toned organ of our sight,
As does that single octave exquisite
Alive with emerald, crimson, and deep blue
(Yet brilliantly enrobed in dazzling white)
Whose harmonies inform our inmost view.

Here, in the first eight lines, four regions of the spectrum are enumerated, two on the long- and two on the short-wave side of visible light; and in the last six, the miracle of human color vision is described with metaphors drawn from music - three-toned organ, octave (the span of

visible wavelengths covers roughly a factor of two), harmonies.

This poem was inspired by a question posed in The Feynman Lectures vol. II Chapter 20-3. "A rainbow looks beautiful to us. Everybody says, Ooh, a rainbow. But if we were blind? [as we are] when we measure the infrared reflection coefficient of sodium chloride One day the physical review of the blind men might publish [an] article [called] The Intensity of Radiation as a Function of Angle under Certain Conditions of the Weather [with] a graph [which] contains much more detail than we apprehend when we look at a rainbow, because our eyes cannot see the exact details in the shape of the spectrum Do we have enough imagination to see in the spectral curves the same beauty we see [in] the rainbow? I don't know." The poem is intended as a negative answer to Feynman's question: it says simply that no other region of the spectrum affects human senses as profoundly as the visible.

Fermions and Bosons

Unique, and yet reprinted o'er and o'er,
Alike, yet e'er alone, I cannot bear
That my own twin be seated in my chair;
Whilst they in even ranks swell more and more,
Wave upon wave, roar upon ocean roar.
Unless tight yoked in a reluctant pair,
The ether knows us not; half spinning there,
My oddly twisted self with self's at war.

Yet, by exclusion, we mark off the space
That bears dark witness to their brilliant flight;
We occupy, make firm, we render place
For their swift bulletins of sound and light.
We make up Nature's brick, they her cement;
We from the nether, they from Heaven sent.

In this poem there is no reference to human beings at all, despite the personal pronouns. "We" refers to fermions and "they" to bosons. The first three lines remark that although all fermions are

identical, no two can occupy the same state. The illusion generally present in the Petrarchian rhyme scheme, that lines 4 and 5 form a rhymed couplet, is here deliberately exaggerated to describe the unlimited amplitude of a bosonic wave. The sixth line alludes to "quasi-bosons" such as a Cooper pair, and the seventh and eighth to the fact that an odd number of rotations bring a fermion into destructive interference with itself.

The last six lines point out how fermions and bosons cooperate in building the universe. Without fermions there would be no spatial extent of physical objects; without bosons there would be no interaction among fermions. (To make it all work, one should regard the quasi-bosons of line six and the excitations called phonons as bosons.)

Friedberg also has a bent for humorous verse. He writes, "This poem is an exercise in reverse doubletalk. The perpetrator of doubletalk slips an occasional nonsensical word or phrase into a context that sounds perfectly normal. In reverse doubletalk the whole context is nonsensical, and the perpetrator slips in a totally lucid passage which is disguised to appear as nonsensical as the rest."

Dark or Bright

Over the weft
under the wabe,
into the sun
and starshine

Heavy or light
dark or bright,
sins like chalk
and sandstone

Wounds that weep
stains that sting,
flowing with milk
and nectar

Dark or bright
colors that bleed,
stains like blood
and chocolate

"Try spotting the reasonable part before looking past all the slashes."

//
//
//
//This poem is entirely meaning-
//less except for the last four//////////////////
//lines, which [at time of ////////////////
//writing] could///////////be found on
//any box of Tide laundry deter-
//gent. They tell which clothes
to //wash in cold///////
//water.////////////////////////
//

"My mentor for this poem, therefore, was not Shelley but the Tide company."

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[1] "Two Recursively Enumerable Sets Not Recursive in Each Other", [solution of Post's problem] , Proc. Nat. Acad. Sci. vol. **43**, p. 236 (1957) [communicated by K. Godel].

[2] "A criterion for completeness of degrees of unsolvability" , Richard. M. Friedberg, Journal of Symbolic Logic, Volume **22**, Issue 2 June 1957 , pp. 159-160

[3] "A Learning Machine: Part I", R. M. Friedberg, IBM Journal of Research and Development (Volume: **2**, Issue: 1, Jan. 1958).

[4] "Three theorems on recursive enumeration. I. Decomposition. II. Maximal set. III. Enumeration without duplication", Richard M. Friedberg , Journal of Symbolic Logic, Volume **23**, Issue 3 September 1958 , pp. 309-316

[5] "Dual Trees and Resummation Theorems," R. Friedberg, J. Math. Phys. vol. **16**, p 20 (1974)

[6] The Electrostatics and Magnetostatics of a Conducting Disc, R. Friedberg, Am. J. Phys vol. **61**, p. 1084 (1993)

[7] Path Integrals in Polar Variables with Spontaneously Broken Symmetry, R. Friedberg, J. Math Phys. vol. **36**, p. 2675 (1995)).

[8] "Correction to Schafroth's Superconductivity Solution of an Ideal Charged Boson System ", R. Friedberg, T. D. Lee and H.C Ren, Ann. Phys. vol. **208**, p. 149 (1991).

[9] "Equivalence between Spin Waves and Lattice Bosons (with Applications to the Heisenberg Model)", R. Friedberg, T. D. Lee and H. C. Ren, Ann. Phys. vol. **228** p. 52(1993).

[10] "Derivation of Regge's Action from Einstein's Theory of General Relativity", R. Friedberg and T. D. Lee, Nucl. Phys. B **242**, 145 (1984).

[11] "Superradiant Damping and Absorption", (with S. R. Hartmann), Phys. Letters 37A **285** (1971).

[12] "Frequency Shifts in Emission and Absorption by Resonant Systems of Two-Level Atoms", (with S. R. Hartmann and J. T. Manassah), Phys. Reports 7C, 101 (1973).

[13] "Superradiant Stability in Specially Shaped Small Samples", (with S. R. Hartmann), Opt. Comm. vol. **10**, p 298 (1974).

[14] "Diagrammatic Technique for Calculating Radiation of Coherently or Incoherently Excited Two-Level Atoms", (with S. R. Hartmann), J. Phys. B **21**, 683 (1988).

[15] "Optimizing Third Harmonic Generation in Gases", (with S. R. Hartmann and J. Manassah), J. Phys. B **24**, 3981 (1991).

[16] "Billiard Balls and Matter-Wave Interferometry", (with S. R. Hartmann), Phys. Rev. A **48** 1446 (1993).

[17] " Efficient Sorting of Genomic Permutation..." S. Yancopoulos, O. Attie, Friedberg, Bioinformatics vol. **21**, pp 3352-59 (2005)

[18] " Compatible Quantum Theory", R. Friedberg, P.C. Hohenberg, Rep. Prog. Phys. **77**, 2014, 092001 - 092035 ; "What is Quantum Mechanics? A Minimal Formulation R. Friedberg, P. C. Hohenberg", Published by Springer-Verlag 21 February 2018 by Springer-Verlag in Foundations of Physics, Feb 21, page 1 (2018).

[19] In 1989, Friedberg wrote five letters to Douglas Hofstadter of which only four have survived[20], [21], [22],[23] (Hofstadter replied about two years later.)These letters include a very in-depth critique and analysis of topics in *Metamagical Themas* – a collection of articles that Douglas Hofstadter wrote for the popular science magazine Scientific American during the early 1980s. There are absolutely

amazing and are a new unique window to Friedberg as a person of many talents...). The three poems included here are from the letter number 5.

[20] <http://physics.gmu.edu/~isatija/R2D2.pdf>

[21] <http://physics.gmu.edu/~isatija/R2D3.pdf>

[22] <http://physics.gmu.edu/~isatija/R2D4.pdf>

[23] <http://physics.gmu.edu/~isatija/R2D5.pdf>