QUANTIFYING THE IMPACT OF PHYSICS THROUGH SCIENTIFIC PUBLICATIONS

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ABSTRACT
I present some of the parameters internationally used to measure the impact of scientific articles, and discuss their advantages and disadvantages. I introduce data related to the impact of scientific work in Physics generated in the area of Latin America, and, specifically, in Cuba. Although this paper cannot be taken as a definitive bibliometric study, I hope it offers some clues to conduct a systematic investigation of the impact of Cuban Physics in the international context, using scientific publications as a measuring tool.

RESUMEN
En este trabajo presento algunos parámetros utilizados internacionalmente para medir el impacto de los artículos científicos, y discuto sus ventajas y desventajas. Introduzco datos relacionados con el impacto del trabajo científico en el campo de la Física generada en el área de Latinoamérica y, específicamente, en Cuba. Aunque este artículo no puede ser tomado como un estudio bibliométrico definitivo, espero que ofrezca algunas ideas sobre cómo conducir una investigación sistemática del impacto de la Física cubana en el contexto internacional, utilizando las publicaciones científicas como herramienta de medición.

1. INTRODUCTION

During a recent visit of Leon Lederman[1] to the Physics Faculty, University of Havana, he presented to our students the hypothetical case of a scientist who is offered all the necessary tools to reach the understanding of the ultimate truths of the Universe. The only condition is that the scientist should be confined to a desert island, and should keep his findings to himself. His firm answer is: NO!. The story has to do with the need of transcendence, an old concern of humans so elegantly posed by Diderot in 1875: "Posterity is, for the philosopher, what the Other World is for the religious man".

In the academic arena, *publication* is one of the highest expressions of the need of transcendence. If in past ages books constituted the typical means to spread original scientific work (remember Galileo's "Dialogues on two new sciences" and Newton's "Principia"), publication of articles in peer reviewed scientific journals constitutes a standard in the contemporary road to scientific transcendence –including in the term, beyond personal recognition, the need of dissemination of frontline knowledge to ultimately improve mankind.

An important aspect of contemporary publications is that they open one way to quantify the impact of the scientific work of a person, or even of a country. I should underline, however, that there are other parameters that can be used for that purpose, such as the % of the National Gross Product devoted to research, the number of scientists per capita, or the number of patents.

In the next sections, I shall describe how the impact of scientific publications is measured, with emphasis in the *impact factor* and *half-life* parameters, and present their values for several journals in the Physical and Chemical sciences. I discuss some limitations of these parameters related to social, cultural and even political issues that unavoidably influence the scientific arena. Then, I shall explain some criteria used to quantify the scientific impact of individuals, based on their publications in peer-reviewed journals. Along the road, I offer data relative to scientific publications by Latin American authors and, specially, Cuban scientists. The latter –still very far from a true bibliometric study– are published by the first time, to the author's knowledge.

2. A COUPLE OF BIBLIOMETRIC INDICES

In a few words, the impact of a scientific paper can be measured by counting how many times and for how long it is cited in later scientific papers. Figure 1 shows two hypothetical graphs illustrating the number of times an average paper published in a scientific journal is cited by other papers published in the same or other journals [1]. The graphs indicate that the number of citations first increase and then slowly decreases.

[1] 1988 Physics Nobel Prize winner for his contributions to the study of neutrino and leptons.

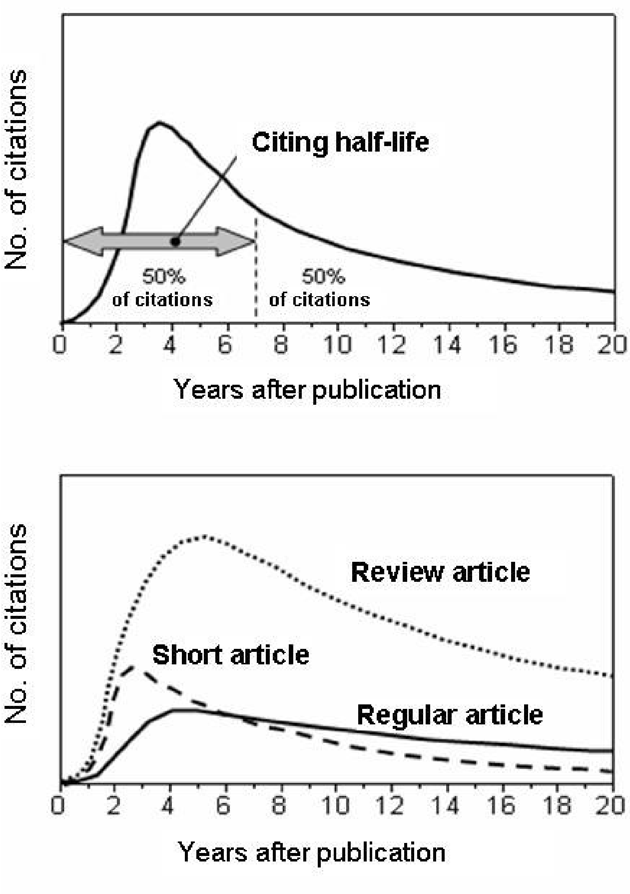

Figure 1. Time evolution of the impact for hypothetical articles.

It must be stressed that Figure 1 shows just an average behavior: there are, for example, "gray" articles that are never cited –unfortunately a case more common than we would like to accept. In fact, the road to a large number of citations does not necessarily follow the hypothetical curves shown in Figure 1. For example, record-citation paper "A model of Leptons", published by Nobel prize winner Steven Weinberg in 1967 has followed a very tortuous path to fame. In a recent article series by James Riordon, the authors analyzes the 10 most cited papers published in the journal *Physical Review Letters* [2]: Weinberg's was paper No. 1, with 4602 citations. The curious thing about this paper is that it received most of its citations only after 1971 *–4 years after its publication*. The reason was the following. The paper proposed a theory establishing a relation between electromagnetic and weak interactions. However, Weinberg was not able to show at that time that the theory was renormalizable, which limited its practical usefulness. Only in 1971 Gerard't Hooft was able to prove it, opening the doors of Weinberg's 1967 paper to the book of records… and giving a final push to Weinberg's nomination to the Nobel Prize in 1979.

Nobody should be surprised by the fact that scientific journals have their own "pedigree": some are regarded more prestigious than others. In this world, where everything is ranked –from MTV music hits to the most relevant personalities of the Millennium–, scientific journals do not escape the mainstream. Amongst the most popular rankings of scientific journals are the ones reported by the U.S.-based *Institute for Scientific Information* (ISI), resting on the analysis of tens of thousands of publications from all over the world.

Let us assume that the graph shown in Figure 1 represents the average time behavior of the citations to papers published in journal X. The time elapsed from the time of publication of the article and the moment when it has reached a 50% of the its total number of citations, is called *citing half-life* of journal X. In the hypothetic example shown in the upper section of Figure 1, its value is 7 years. This parameter gives an idea of the permanence in the scientific scenario of the papers published in journal X. So, it might be said that a large half-life journal publishes papers that tend to "make History".

However, a different parameter is the one used to establish the ranking of scientific journals: the *impact factor*, introduced by ISI in the 1960's [3]. The impact factor of journal X is the average number of citations per year that an average paper of journal X receives, within a given interval of time after the publication of the article. For example, if journal X has published 500 papers during 1997 and 1998, and those articles have received a total of 1000 citations during 1999, the impact factor of journal X during 1999 is 1000/500 = 2.00. Of course, the articles published in a journal with high impact factor strongly attract the attention of the scientific community.

From now on, I will call "IF04" the impact factors reported by ISI in 2004, and "<IF>", the impact factors averaged within the period 1974-2000 [4][2].

In the field of Physics, the review article journal *Reviews of Modern Physics* (IF04 = 32.77; <IF> = 16,61) boasts the highest absolute impact factor, while *Physical Review Letters* (IF04 = 7.22; <IF> = 6,57) has the highest impact factor amongst the journal publishing original papers in the field of Physics. In both cases, numbers are supported by an established prestige: while future Nobel winners tend to publish in *Physical Review Letters* some of their key original results, their Nobel lectures tend to be published in *Reviews of Modern Physics*. *Applied Physics Letters* (IF04 = 4.31; <IF> = 3,42) is the most important journal in the field of the applications of Physics. Finally, it is worth noting that *Nanoletters*

[2]We have taken this particular period since the full data can be accessed freely in the webpage of reference [4], and because it comprises the lapse where many of the Cuban papers in those journals were published.

(IF04 = 8.45) –devoted to the "hot" area known as nanoscience– has emerged as a key journal in the fields of Physics and Chemistry in the last years.

3. LIMITATIONS OF IMPACT FACTORS

3.1. The issue of diversity

While the prestige of the publications mentioned above is very well established, it is dangerous to evaluate the importance of a given journal only by the size of its impact factor. One of the elements that make any comparison difficult is that there are journals specialized in the publication of just one type of article. While most scientific journals publish *original papers* of medium or short sizes, some specialize just in short contributions –like *Physical Review Letters* and *Applied Physics Letters*– and others only in review articles, such as *Reviews of Modern Physics*. Figure 1 suggest that articles appearing in the former type of journals tend to receive many citations in a very short time, while those published in the latter ones receive a large number of citations, but distributed within a longer period of time. The editors of review journals often invite recognized scientists to write papers that examine an entire subfield of the discipline, typically pointing out strengths and weaknesses, and proposing future lines of research. Those papers are popular amongst researchers entering a given field of research, and eventually tend to shape the scientific work of a scientific community.

The existence of different disciplines associated to diverse scientific communities constitutes another obstacle to compare scientific impacts based exclusively on the impact factor. For example, there are areas that generate a huge amount of citations due, amongst other things, to the great number of scientists involved: Medicine and Pharmaceutical Science are two examples. It is not strange that a scientific paper reporting a new drug or medical procedure is cited many times due to the fact that the new drug or procedure is statistically studied in hundreds of hospitals, producing new publications. It is my opinion, however, that some comparisons are reasonable among the exact sciences, which is supported by the compilation of average impact factors of Physics and Chemistry journals illustrated in Table 1. It shows that the impacts within the different ranges selected are quite similar, perhaps with some "advantage" by Chemistry journals. Appendix 1 contains a list of the impact factors in the period 2000-2004 of most of the journals shown in Table 1. Some of them are not listed either because they disappeared, or because their impact factors have decreased below 5.00. Some new journals have been added to the list, in the light of their high impact factor during the last years.

3.2. Scientific prejudices

Another element that makes difficult the comparison of scientific results exclusively by means of impact factors is the "scientific prejudices" of the community involved –composed, after all, by humans.

Table 1. Comparison between the impact factors of some Chemistry and Physics journals (averages taken within the period 1974-2000).

CHEMISTRY	PHYSICS
⟨IF⟩ > 10	
12.50 CHEM REV 11.59 ELECTROANAL CHEM 11.43 SURF SCI REP 10.91 ORG REACTIONS	16.47 REV MOD PHYS 12.61 SOLID STATE PHYS 11.43 SURF SCI REP
10 > ⟨IF⟩ > 9	
9.33 ACCOUNTS CHEM RES 9.38 PROG INORG CHEM	9.71 ADV PHYS 9.96 ANNU REV ASTRON ASTR
9 > ⟨IF⟩ > 8	
8.55 PROG PHYS ORG CHEM 8.26 ADV ORGANOMET CHEM 8.25 ADV CHEM PHYS	8.25 ADV CHEM PHYS 8.02 ADV NUCL PHYS
8 > ⟨IF⟩ > 7	
7.99 ADV INORG CHEM 7.93 ADV CYCLIC NUCL RES 7.18 ADV INORG CHEM RAD 7.02 ANNU REV PHYS CHEM	7.10 PHYS REP 7.02 ANNU REV PHYS CHEM
7 > ⟨IF⟩ > 6	
6.78 ADV PHOTOCHEM 6.47 ADV PHYS ORG CHEM 6.24 ADV CATAL 6.02 STRUCT BOND 6.04 TOP STEREOCHEM	6.57 PHYS REV LETT 6.43 J HIGH ENERGY PHYS
6 > ⟨IF⟩ > 5	
5.63 Z ANGEW CHEM INT EDIT 5.59 CHEM SOC REV 5.45 MASS SPECTROM REV 5.30 ORGANOMET CHEM REV A 5.29 MAT SCI ENG R 5.12 J PHYS CHEM REF DATA 5.00 PROG MACROCYCL CH	5.82 EUR PHYS J C 5.81 REP PROG PHYS 5.45 MASS SPECTROM REV 5.29 MAT SCI ENG R 5.12 J PHYS CHEM REF DATA

Scientific prejudices influence, of course, where and when a discovery is published, and also the attention it receives by the scientific community. A good example is the publication of the discovery of high temperature superconductors (HTc's). During the

1950's, much respected BCS theory established an upper limit for the critical temperature of a superconductor. No experimental physicists in his (or her) right mind would dare to attempt to find a superconductor with a critical temperature above approximately 30 degrees Kelvin (30 K). One exception was Alexander Müller, from IBM at Zürich, who had been quietly working en perovskite-type materials, where he suspected superconductivity could be found. After years of work with his colleague Johannes Georg Bednorz, they managed to synthesize a ceramic material with a critical temperature near 35 K. Perhaps due to the possibility of a negative reaction of the physics community, the results were published in 1986 under the low-profile title "Possible High-T_c superconductivity in the Ba-La-Ca-O system", in *Zeitschrift fur Physik* – a journal with a relatively modest impact factor (<FI> = 2,32) if compared, for example, with *Physical Review Letters*. In fact, the paper was unnoticed for most of the scientific community.

Fortunately C. W. Chu, from the University of Houston, understood the importance of the result, and started to investigate frantically related compounds with the collaboration of colleagues from the University of Alabama. It resulted in the discovery of a ceramic superconductor with a critical temperature higher than 90 K (i.e., above the boiling point of nitrogen, a very important achievement for applications). The result was rapidly published in *Physical Review Letters* in 1987, under the strong title "Superconductivity at 93 K in a new mixed-phase Y-B-C-O compound system at ambient pressure", and produced an instantaneous earthquake in the field of Physics. The climax was reached shortly after the publication of the paper, in a round-the-clock meeting in New York known as the "Woodstock of Physics", in analogy with the legendary rock festival of 1969. The importance of Bednorz and Müller's paper in *Zeitschrift fur Physik* finally became widely acknowledged, and the authors received the Nobel prize in Physics in 1987 [5].

3.3. Idiomatic limitations

As in many other aspects of social life, historical periods have been marked by the domination of certain cultures also in the scientific arena. Consequently, certain languages have dominated science in different eras. In the XIX century the languages of the most developed European countries dominated science: English, German and French. That situation changed dramatically after Second World War with the exodus from Europe to the United States of scientists of Jewish origin and from other ethnical, political and religious backgrounds persecuted by the Nazis [6]. Physicists Albert Einstein and Enrico Fermi are perhaps the most relevant amongst them. The result was the transformation of the U.S. into a super-power in Physics from the second half of the XX century. This situation undoubtedly contributed to the domination of scientific publications *in English*, edited, in the case of Physics, by the main U.S. in the field: The *American Physical Society* (publishers of *Reviews of Modern Physics, Physical Review Letters*, etc.), and *The American Institute of Physics* (publishers of *Applied Physics Letters*, etc.).

Although most referees and editors of prestigious scientific journals work under high professional and ethical standards, some of them recognize that a manuscript containing idiomatic defects can influence an editorial decision. The rationale is the following: "if the authors have been careless with grammar and spelling, why should one discard that they have been also careless in their experiments or calculations?" [7]. That reasoning is, of course, valid to some extent. But, at any rate, non-English speaking scientists have nowadays *two* barriers to overcome when writing a scientific paper: the difficulties of science itself, *and* those of a foreign language.

3.4. Economical, social and political issues: The Geography of scientific impact

Some scientific journals publish papers in all the branches of science. Amongst them, *Nature* (IF04 = 32.18; <IF> = 16,07) and *Science* (IF04 = 31.85; <IF> = 14,68), are the most prominent ones. They reject between 90 and 95% of the manuscripts they receive, and a sizable amount of their decisions are purely editorial (i.e., the papers are not examined by referees). Beyond the numerical values of their impact factors, most scientists agree that they are the most visible journals in the field of natural sciences. Based on statistics of 1994, approximately 85% of the papers published by *Science* were signed by authors from an "elite" of countries: United States (~20%), United Kingdom (~17%), France (~15%), Germany (~14%), Canada (~12%) and Japan (~7%). Scientific powers like Russia or China modestly contributed to the remaining percent [7].

Regarding the "global" geography of high impact papers authored by Third World and, particularly, by Latin American scientists, the global situation can be easily predicted. The share of the latter in the scientific production in all fields of science, measured through the number of papers in indexed journals is less than 5% of the world production [8]. Although I do not have data for Cuba embracing publications in all indexed journals at the time of writing this paper, it is safe to say that, in spite of the declining economy of the early 1990's, our scientific community have started to increase its share of publications in internationally recognized journals ever since, achieving more and more space and impact.

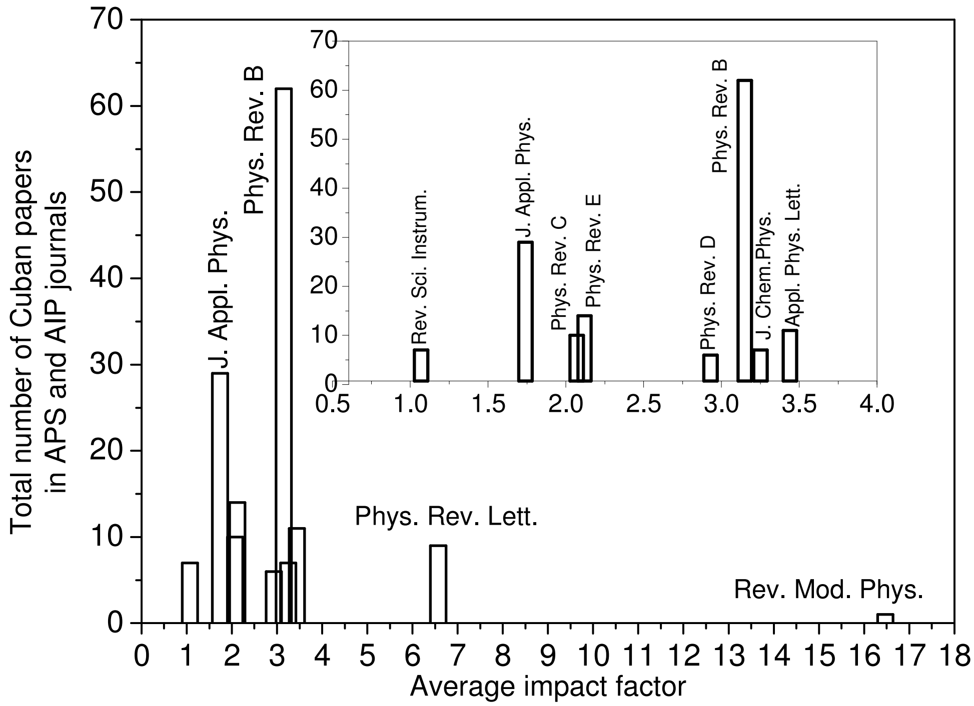

Figure 2. Number of articles appeared in APS and AIP journals, signed by physicists working in Cuban institutions (period 1994-2004).

Figure 2 shows some data extracted from the American Physical Society (APS) and American Institute of Physics (AIP) websites, related with articles published in the period 1994-2004 on journals edited by those organizations, where several of the most prestigious journals in Physics are included. I have only included in the statistics the hits returned when the word “Cuba” is typed in the space “affiliation” of the searching engine. Since the search is free, I invite the reader to perform his (or her) own investigation. Notice that my selection criterion has several clear limitations, such as neglecting important journals (those edited by *Elsevier Science*, to put one possible example), but also some less evident, such as neglecting papers where Cuban researchers signed as members of the foreign institution where they where doing scientific work at the time of the publication. As a complement to Figure 2, Table 2 shows the data of the first Cuban publications appeared in APS and AIP journals, selected by using the search criterion described above.

It is worth noting that, in a first approximation, 80% of the publications comprised in Figure 2 are signed by at least one author from the University of Havana (basically from the Physics Faculty or from the Institute of Materials and Reagents), while the remaining 20% is roughly shared by the ICIMAF and the InSTEC (also Havana-based institutions), with a number of small contributions, specially from Las Villas Central University. Authors from the University of Havana are also involved in 70% of the “pioneering papers” of Table 2. The inspection of the list of papers comprised in Figure 2 and Table 2 are two-fold alarming. First, they show an overwhelming concentration of Physics authors in Havana. Second, there is a relatively small number of authors contributing to those papers within each institution.

Table 2. First papers published in APS and AIP journals where the word “Cuba” appears as “affiliation”.

Journal	<IF>	Reference
J. Chem Phys.	3.25	**31**, 467 (1959)
Appl. Phys. Lett.	3.44	**46**, 853 (1985)
J. Appl. Phys.	1.74	**59**, 2114 (1986)
Phys. Rev. B	3.15	**37**, 4583 (1988)
Phys. Rev. D	2.93	**40**, 1255 (1989)
Phys. Rev. E	2.12	**49**, 4027 (1994)
Phys. Rev. Lett.	6.57	**76**, 42 (1996)*
Phys. Rev. C	2.07	**55**, 2471 (1997)
Rev. Sci. Instrum.	1.07	**69**, 3634 (1998)
Rev. Mod. Phys.	16.47	**76**, 471 (2004)

*It is important noting reference 67, 2335 (1991), where a

Cuban author has not signed “Cuba” as “affiliation”, but as “permanent institution”.

But let us go back to the effect of economic limitations on the impact of publications generated from Third World countries. One evident effect is the one resulting from lack of material support and ageing of available equipment. A glance at the contents of the papers contained in Figure 2 reveals also “second order” effects. For example, 70% from the total of papers are “theoretical” and only a 30% involve experimental work. While 60% of the theoretical papers are exclusively signed by Cuban institutions, the same number for experimental papers is as small as a 15%. These approximate figures suggest two tendencies in Cuban contemporary Physics –at least the one published in some of the highest impact journals. First, the prevalence of “theoretical” investigation (defined as that where no direct experimental work is involved) Second, that the experimental work depends heavier on foreign collaboration than the theoretical one. An interesting analysis of these and other elements has been presented in an article recently appeared in the Physics Today, September 2006, p. 42.

Although these tendencies are no surprising for the majority of my readers, here we have been able to quantify them, at least partially, with the help of bibliographic databases. Finally, it is worth noting that the great proportion of papers published by Cuban authors in *Physical Review B* certainly reflects the high volume of scientific work in Solid State Physics, specially semiconductor physics.

Figure 3 attempts to quantify the evolution of the *impact* of the publications accounted in Figure 2. The vertical axis corresponds to the “total average impact” for each year within the period 1994-2004, defined as:

$$FI_T = \sum_{i=1}^{N} FI_i$$

where N is the total number of articles published during a certain year, and FI_i is the average impact factor [4] of the journal where paper i was published. Notice that a systematic increase of the total impact of Cuban publications in the journals under analysis starts quite sharply in 1996. If we fit it to a straight line in the period 1996 - 2004, the slope is approximately 6 impact units per year. Some questions immediately arise: is the 1996’s “awakening” connected to the “recovery” of the Cuban economy from the lowest point of its crisis, known as “the special period in peace time”?. Is it connected with the widening of the relations with “the West” that took place in the same period and holds until today? Or it is perhaps related to the increasing “expertise” of Cuban researchers in the “art” of publication in international scientific journals? Should we expect this tendency to continue within the next years?

Other elements related to the economy that conspire against scientific productivity is the lack of continuity of our own scientific publications, which makes difficult to fulfill the requirements to be indexed in international databases. To the author’s knowledge, the only Cuban journal indexed by ISI is the *Cuban Journal of Agriculture* (*Revista Cubana de Agricultura*). The Cuban Journal of Physics (*Revista Cubana de Física*) was founded in 1981. After an period of irregularities during the 1990´s, it has been revitalized, including the preparation of a database with the totality of the numbers since its foundation.

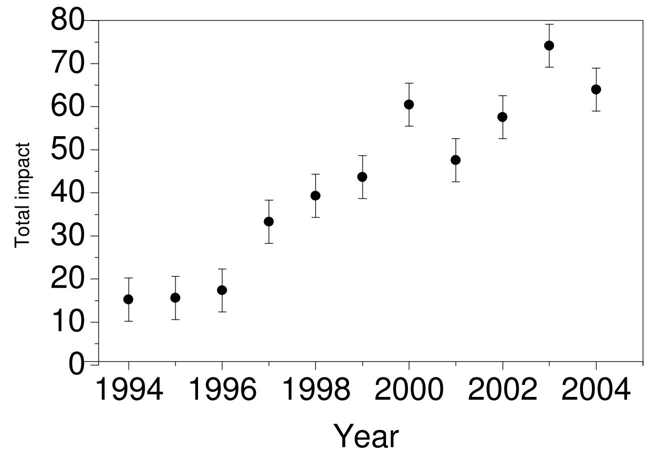

Figure 3. Total impact of articles appeared in APS and AIP journals, signed by physicists working in Cuban institutions (period 1994-2004).

Another element indirectly related with economy that influences the impact of Physics can be posed as another question: to what extent the brain drain to the most developed countries influenceS the impact of publications by Third World countries in Physics?. As far as I know, there is no trustable statistics to construct an answer. But one can safely say that, within the last 20 years, it is easy to identify an increase in Chinese names, and, since the early 1990’s, in Russian names, on scientific papers signed by first-world institutions. In the case of Cuban Physics I would say that a glance at the list of authors of the papers included in Figure 2 allows identifying a number of names that are nowadays signing their papers as members of foreign institutions –mainly European, Brazilian or Mexican–, a situation that has increased during the last 10 years. However, there is a “hard core” of Cuba-based physicists that, in spite of many difficulties, has managed to keep an increasing presence in the world of high-impact scientific publications.

In the area of “non-economic” factors conspiring against the scientific productivity measured through publications in indexed journals, there are also “endemic prejudices”. One example is the relatively small importance given to publications in indexed journals as a way to measure scientific productivity of individuals and institutions, mainly before the 1990's. That tendency is somehow associated to the strong will to drive scientific work towards *direct* economical applications, sometimes resulting in useful technological research of marginal scientific quality. It might be also linked to the difficulties to use the impact of scientific articles as a single standard for natural sciences and for social and economical sciences, where publication in indexed journals can be handicapped by ideological and political considerations. I do not subscribe, however, the idea that the production and impact of publications should be taken as the *only* measuring standard for scientific proficiency.

An extreme that illustrates how political issues can influence scientific publications from third world countries, is a recent "reinterpretation" of the U.S. embargo laws against a number of countries (Cuba amongst them) saying that manuscripts submitted to U.S. journals from those countries could not be edited by them. An editor would not, in principle, correct the grammar or spelling of a paper submitted, say, by an Iranian or Cuban author. In practice, it would mean freezing any paper from the embargoed countries submitted to the journal. Some Cuban manuscripts were reportedly frozen by indexed journals in the process. The decision was subject of protest by the international scientific community, as it was regarded an offense to scientific ethics (9), resulting in its dismissal, at least *de facto*. Differently from other scientific organizations, it should be said that the *American Physical Society*, the *American Institute of Physics*, and the *American Society for the Advancement of Science* (which publishes *Science* magazine) refused from the very beginning to accept the prohibition. My own experience is that APS never hesitated even during the editing process of its top-visibility journals, even at the worst of the "crisis".

Beyond the abyss between developed and developing countries, the differences in economical and political power amongst highly developed countries shows clear fingerprints in the impact of scientific journals, especially after II World War. In the field of Physics, even when the European Physics Society has tried to challenge the domination of *Physical Review Letters* by pushing forward its equivalent *Europhysics Letters*, the attempt has failed –at least for the time being– since the latter has been unable to surpass an impact factor of approximately half of that of *Physical Review Letters*. APS journal *Reviews of Modern Physics*, on the other hand, is well beyond any competitor in the field of Physics (and in most scientific fields), with an impact factor of 32.7 in 2004.

4. QUANTIFYING THE INDIVIDUAL IMPACT

In "highly competitive" scientific markets, the individual impact measured through scientific publications is often used to hire professionals, to decide promotions and, eventually, to get research grants and projects –particularly international ones. In the case of Cuba, it is used as an element to grant prizes and small financial support through projects – sizable support for science is basically decided on other grounds, though. In any case, I believe that the scientific impact measured through scientific publications is a useful tool to self-evaluate the reach of one's scientific work. Table 3 –inspired on some elements reported in reference 10– includes a number of useful parameters that quantify the individual scientific impact, as well as some of their advantages and disadvantages:

Criteria in Table 3 would deserve an extensive analysis, but I will restrict myself to mention three examples indirectly related to the discussion. Few persons would hesitate to classify as "geniuses" writer Miguel de Cervantes and musician Joaquín Rodrigo. However, they earned such status *basically on a single work:* the novel popularly known as "El Quijote" and the musical piece "Concierto de Aranjuez". Something similar can be stated about physicist Luis de Broglie and his wave-particle duality.

I would add further criteria that might be useful in the Cuban context. There, where so many international collaborations take place, sometimes the role of the foreign counterpart does not reduce to the pure scientific collaboration or to provide part of the material support, but includes the control of the very publication process: elaboration of the manuscript, exchange with the editors, and response to the referees. Such tendency delays the development of publishing skills by Cuban scientists. So, a relevant index to quantify the "autonomy" of our authors (we might call it "scientific tropicality factor, STF"), would the number of the articles where Cuban scientists are "corresponding authors", or the number of citations those papers have received.

With the aim to eliminate the disadvantages of many of the criteria included in Table 3, J. E. Hirsch has recently proposed a new parameter to measure individual scientific work: *the h-index* (10,11). *A scientist possesses an index h, if h of his (or her) papers have been cited, at least, h times* (the remaining papers have been cited less times). Figure 4 illustrates a way to visualize the h-index. The horizontal axis contains the number of papers by the author in question, starting by the one that has received a maximum number of citations. The vertical axis contains the number of citations corresponding to each of the papers in the horizontal axis. Then, the area under the curve corresponds to the total impact of the articles published by the researcher. If now we draw a 45 straight line crossing the origin of coordinates, both the “x” and “y” coordinates of the intercept between the straight line and the curve correspond to the *h* index.

Assuming a “linear” model (i.e., the researcher produces articles of a similar impact, at a fixed rate along his (or her) career), it can be shown that the index h is given by (10):

$$h \sim mn$$

where n is the year, and m is a number that depends on the researcher. It means, of course, that it is m, the parameter that allows comparison between researchers of different ages. Within the linear model, m is given by (10):

$$m = \frac{c}{1+\frac{c}{p}}$$

where p is the number of papers per year published by the researcher, and c is the number of new citations that each of those papers receives each year. As most linear models applied to “social” phenomena, this one pictures reality in an oversimplified fashion: a glance at curves in Figure 4 demonstrates how far from reality the model can be.

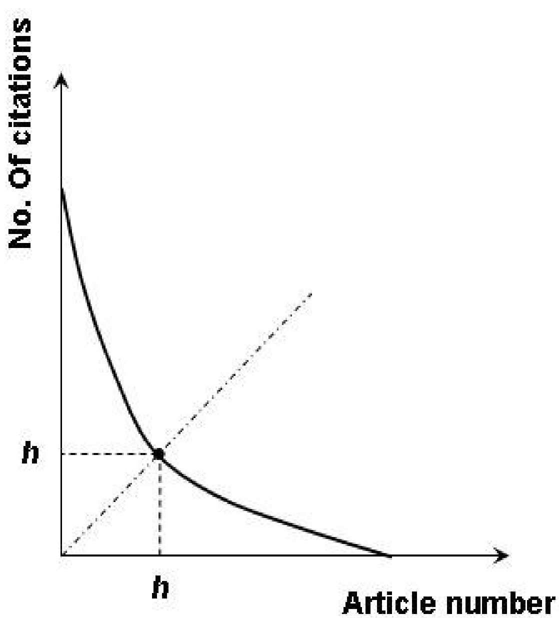

Figure 4. Visualizing the h-index.

Beyond models, straight calculations of m and h based on hard data give encouraging results about their capacity to quantify the quality and quantity of individual scientific work. In fact, until August 2005, the top m and h indices in Physics corresponded to Ed Witten (h = 110, m = 3.89). Following Hirsch, m ~ 1 (i.e., h ~ 20 after 20 years of scientific work) is a fingerprint of a successful scientist, while m ~ 3 (i.e., h ~60 after 20 years of scientific work) corresponds to truly unique individuals.

A further element that supports the choice of m and h indices is that 84% of Nobel winners in Physics with papers published in journals indexed by ISI have a h factor of, at least, 30. Following Hirsch (10) it indicates that the Nobel Prize is not just the result of a struck of luck, but of sustained scientific work.

CONCLUSION

In my opinion, the advantages to quantify the scientific impact based on the publications in indexed journals are beyond any doubt. Cuban scientists and, specially, Cuban physicists, are encouraged to increase the quantity and quality of their contributions to indexed journals, and then increase the relative position of our country in that field, at least within the Latin American context. Considering the material limitations in which our scientific work takes place, the only way is to put on it an extra dose of originality, and to increase our professionalism in the art of publication of new results: sensible paper writing, wise selection of the target journal, and intelligent management of the editorial process.

Although the impact factor and other bibliographic indices are unavoidable parameters to measure the real impact of science, they cannot be taken as the only way to measure the scientific results of an individual, and institution, or a country. In the latter case, other numbers as the % of the National Gross Product devoted to research and the number of scientists per capita should be also taken into account[1]. Other non-quantifiable factors such as the social or cultural impact of a scientific discovery are extremely relevant[2].

Finally, I would like to stress that this article does not pretend to constitute an exhaustive bibliometric study of the impact of Cuban Physics: for one thing, the sample of publications under analysis has been very limited. It would be excellent if a real expert performs a definitive study on the subject, which would surely contribute to evaluate the international impact of Cuban Physics, and its perspectives in the short and medium terms.

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Table 3. Some criteria to evaluate the individual scientific impact.

CRITERIA	ADVANTAGES	DISADVANTAGES
Total number of papers published in indexed journals	Measures lifetime productivity	It does not measure the true impact of papers, it does not allow to compare scientists from different ages
Total number of citations of published papers	Measures total impact in a lifetime	Can be “inflated” with a few highly cited papers, where the scientist may have had small contribution. I does not allow to compare scientist from different ages
Number of citations per paper	Allows to compare scientists from different ages	Penalizes high productivity (assuming that producing a small number of papers with very high impact is a bad idea!)
Number of “most relevant” papers	It concentrates attention on what is important	The quality of the papers taken as “relevant” is arbitrary. In general, the selection criteria must be adapted somehow to the age of the scientist. It does not give a true image of the whole scientific career of the individual
Number of citations of each of the “most relevant” papers	It concentrates attention on the impact of relevant scientific work	Besides the disadvantages of the former criteria, this one is not described by a single number

APPENDIX

Impact of some Physics and Chemistry journals within the period 2000-2004[3]

Journal	IF2000	IF2001	IF2002	IF2003	IF2004	<IF00-04>
REV MOD PHYS	12.774	12.762	23.672	28.172	32.771	**22.030**
ANNU REV ASTRON ASTR				16.000	18.839	
SURF SCI REP	14.952	14.091	13.238	12.650	21.35	**15.256**
ADV PHYS	13.611	16.200	13.952	13.087	15.333	**14.437**
PROG MATER SCI*	4.667	14.000	11.600	12.00	10.467	**10.547**
ANNU REV PHYS CHEM	9.237	7.609	10.255	10.500	11.944	**9.909**
SOLID STATE PHYS	9.250	9.667	6.600	7.000	16.000	**9.703**
MAT SCI ENG R	6.083	6.143	11.893	10.032	14.233	**9.677**
PHYS REP	7.110	8.341	12.645		14.742	
REP PROG PHYS	9.000	8.879	7.618	8.409	7.842	**8.349**
MASS SPECTROM REV	7.600	8.391	6.750	7.364	8.743	**7.769**
ANNU REV NUCL PART S*	5.040	6.690	7.179	8.667	7.739	**7.063**
ADV NUCL PHYS	4.667	6.667	10.571	8.750	4.500	**7.031**
PHYS REV LETT	6.462	6.668	7.323	7.035	7.218	**6.941**
ADV MATER*	5.522	5.579	6.801	7.305	8.079	**6.657**
J HIGH ENERGY PHYS	4.196	8.664	6.854	6.057	6.503	**6.455**
ANNU REV FLUID MECH*	6.486	5.486	6.450	5.108	6.694	**6.045**
PROG NUCL MAG RES SP*	5.062	7.192	4.808	5.971	6.885	**5.984**
NUCL PHYS B*	4.225	6.226	5.409	5.297	5.819	**5.395**
J PHYS CHEM REF DATA	8.756	4.488	3.333	4.000	4.788	**5.073**
ADV ATOM MOL OPT PHY*	4.941	4.576	4.524	4.107	7.214	**5.072**
PHYS TODAY*	**5.298**	**4.790**	**5.000**	**5.020**	**5.211**	**5.064**

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[1] A recent study by RAND based on these and other parameters classified Cuba as a “scientifically proficient” country (12).

[2] A beautiful example that shows how top-quality science combines social usefulness with bibliometric impact, is the recent development of a fully-artificial vaccine by a Cuban team of researchers (***Science*** 305 (2004) 522).

[3] The symbol <IF00-04> corresponds to the impact factor averaged over the period 2000-2004. Only journals with <IF00-04> higher than 5.00 have been included in the tables.

Chemistry

Journal	IF2000	IF2001	IF2002	IF2003	IF2004	<IF00-04>
CHEM REV	20.036	21.044	20.993	21.036	20.233	**20.668**
SURF SCI REP	14.952	14.091	13.238	12.650	21.35	**15.256**
ACCOUNTS CHEM RES	13.262	12.781	15.901	15.000	13.154	**14.019**
PROG MATER SCI*	4.667	14.000	11.600	12.000	10.467	**10.547**
ANNU REV PHYS CHEM	9.237	7.609	10.255	10.500	11.944	**9.909**
CHEM SOC REV	10.747	9.137	8.718	9.569	10.836	**9.801**
MAT SCI ENG R	6.083	6.143	11.893	10.032	14.233	**9.677**
PROG INORG CHEM	10.714	16.500	4.286	8.500	7.200	**9.44**
ADV CATAL	11.000	6.846	10.923	7.889	9.75	**9.282**
ANGEW CHEM INT EDIT	8.547	8.255	7.671	8.427	9.161	**8.412**
MASS SPECTROM REV	7.600	8.391	6.750	7.364	8.743	**7.769**
CATAL REV*	6.562	8.471	6.455	5.708	9.750	**7.389**
ALDRICHIM ACTA*	5.900	7.846	6.333	7.077	8.833	**7.198**
ADV ORGANOMET CHEM	9.588	7.417	5.467	7.200	5.500	**7.034**
ADV MATER*	5.522	5.579	6.801	7.305	8.079	**6.657**
ADV INORG CHEM	11.545	9.567	3.933	4.095	3.769	**6.582**
NAT PROD REP*	5.295	5.772	5.900	7.529	7.89	**6.477**
J AM CHEM SOC*	6.025	6.079	6.201	6.516	6.903	**6.345**
PROG POLYM SCI*		3.738	7.279	7.759	8.482	
ADV POLYM SCI*		6.053	5.389	6.955	7.320	
PROG NUCL MAG RES SP*	5.062	7.192	4.808	5.971	6.885	**5.984**
TOP CURR CHEM*	5.960	5.800	5.000	5.784	5.283	**5.565**
COORDIN CHEM REV*	3.763	5.224	5.853	5.951	6.446	**5.447**
J PHYS CHEM REF DATA	**8.756**	**4.488**	**3.333**	**4.000**	**4.788**	**5.073**

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