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# Spotlight on Graphene Research from the Middle East

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# GRAPHENE



SPOTLIGHT ON  
GRAPHENE RESEARCH  
FROM THE MIDDLE EAST

# **Spotlight on Graphene Research from the Middle East**

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## Abstract

In an extension to the 2011 article “Reviews of Science for Science Librarians: Graphene” (Lehman 2011), this paper seeks to continue exploring the trend of graphene research but limits its focus to the research production of countries in the Middle East. In addition to reporting on the research output of this group of countries, this article will also examine the most prolific Middle Eastern graphene authors, their supporting institutions and funding agencies, the most cited publications from this group, the journals most used for publication of their work, and the general trend in graphene research growth in the Middle East. As with any publication or citation study, there are limits on the data gathered based on the subscriptions available to the author and based on the imperfect nature of database indexing. The author acknowledges these limitations and tries to explain them; she presents the results not so much as exact numbers but as an approximation and an overview of the trends of graphene research in the Middle East.

## Graphene

First isolated in 2004 by researchers Andre Geim and Konstantin Novoselov, graphene has become the subject of a rapidly growing body of research (Nobel Media AB 2010). Prior to that time, publications on graphene were primarily theoretical. The rate of graphene-related publication, which since 2004 has included more and more experimental results, has increased even more rapidly since 2010. It was that year that Geim and Novoselov were awarded the Nobel Prize in Physics for their work with graphene. The background explanation for the Nobel Prize notes: “They have succeeded in producing, isolating, identifying and characterizing graphene” (Nobel Media AB 2010, p.1). One of the primary characteristics of graphene which made its identification so difficult is that graphene is transparent. Geim and Novoselov found, however, that when graphene is placed on a very thin (300nm) wafer of silicon dioxide, an interference pattern is created that allows the graphene to be seen (Geim and Novoselov 2007).

Graphene, simply defined, is a sheet of carbon atoms that is only one atom thick. It is a fascinating material because of the combination of its properties: graphene is remarkably strong, very flexible, and has high electrical conductivity within the plane of the sheet (Lee, Wei, Kysar, and Hone 2008; Nobel Media AB 2010; Spyrou and Rudolf 2014). For further background reading on graphene, the author suggests: “The rise of graphene” by Geim and Novoselov, “The Nobel Prize in Physics 2010 - advanced information” by Nobel Media AB, and “Reviews of science for science librarians: Graphene” by Lehman.

## Search Methods

For the purposes of this study, the fourteen Middle Eastern countries included are: Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, and Yemen. Bahrain, Palestine, and Syria were also originally considered but yielded no results in the original searches. The author used databases available on the Thomson Reuters Web of Science platform to run searches and gather data. The search results are obviously constrained by the subscriptions and holdings purchased by the author’s institution, which, in this case, is the University of Arkansas, Fayetteville in the United States of America. This concern is minimal, however, because of the topical holdings to which the University of Arkansas subscribes and because the concern of the study is with the research growth and output of countries and authors in relative terms rather than in absolute numbers. To begin the data gathering, the author conducted two identical searches using two different sets of Thomson Reuters databases. The basic search was composed as graphene in the topic field + [Country Name] in the address field. The number of results was noted without further analysis. The basic search was completed for each of the countries listed above. The searches were first run in the “All Databases” option and then repeated with only the “Web of Science Core Collection” selected. For the University of Arkansas, All Databases includes: Web of Science Core Collection (1945 – present), Biological Abstracts (1969 – present), Inspec (1898 – present), KCI-Korean Journal Database (1980 – present), MEDLINE (1950 – present), SciELO Citation Index (1997 – present), and Zoological Record (1978 – present). More specifically, Web of Science Core Collection includes: Science Citation Index Expanded (1945 – present), Social Sciences Citation Index (1956 – present), Arts and Humanities Citation Index (1975 – present), and Conference

Proceedings Citation Index – Science (1990 – present). The author wanted to take advantage of the “Analyze Results” features available in the Web of Science Core Collection that are not available in the All Databases search results. The author did not, however, want to limit to just the Core Collection if the search results in All Databases differed significantly from the results of the Core Collection. This concern was allayed, however, since these searches completed in the two groupings of the databases gave similar results in terms of the ranking of the countries by number of items published (see Table A). For this reason the author was comfortable using only the search results from the Web of Science Core Collection to further analyze the data. Using the features available on the Web of Science platform, the author used the save “Save History” feature to combine all the results from the graphene +[Country Name] searches and then used the “Analyze Results” and “Create Citation Report” to gather more details about the publications as a whole.

## Results

While the two versions of the searches described above (once with “All Databases” and repeated with “Web of Science Core Collection”) gave different results in terms of the raw number of records retrieved, the relative rankings stayed the same with the exception of Yemen and Lebanon. Yemen had six results in both searches while Lebanon had seven in All Databases and only five in the Web of Science Core Collection.

Table A: Search results by country

search <i>graphene</i> in topic + [Country Name] in address	Search in All Databases	Search in WoS core	Rank in All Databases	Rank in WoS Core
Iran	1160	1107	1	1
Saudi Arabia	412	371	2	2
Turkey	317	300	3	3
Israel	223	196	4	4
Egypt	109	100	5	5
U Arab Emirates	45	44	6	6
Iraq	20	20	7	7
Cyprus	17	15	8	8
Qatar	14	13	9	9
Oman	11	9	10	10
Jordan	7	6	11	11
Yemen	6	6	13	11
Lebanon	7	5	11	13
Kuwait	3	3	14	14
Bahrain	0	0		
Palestine	0	0		
Syria	0	0		

It should be noted that duplication and false hits in the search results do exist due to collaborating researchers or overlapping address names. For example, while the paper “Coupling enhancement of split ring resonators on graphene” has three authors (Cakmakyapan, Caglayan, and Ozbay 2014), they are all from Turkey and will only be retrieved in the graphene + Turkey search and only be counted once when all the country searches are considered together. Most collaboration between authors did not impact the search results because the collaboration was with authors from countries outside of the Middle East such as China, Belgium, or Malaysia. But considering the article “Graphene/SnO<sub>2</sub> nanocomposite as an effective material for saline water desalination using capacitive deionization,” four countries are represented by the authors: South Korea (El-Deen, Barakat, and Kim), Egypt (Barakat and Khalil), Saudi Arabia (Khalil), and Iraq (Motlak). While the author affiliation of South Korea does not have an impact on the search that is the concern of this article, the other affiliations will cause duplicated search results by appearing in the search results for Egypt, Saudi Arabia, and Iraq. This duplication, however, is not common and appeared only three times in the first 100 results of the combined searches (when sorted by most recent publication date), with the two other instances having only a two-way overlap between Middle Eastern authors in an Iran/Iraq collaboration and a Kuwait/Egypt collaboration. As for false hits, in the indexing for the article “Polymer/carbon nanofillers films fabricated by latex technology” the author address for R. Y. Suckeveriene is “Kinneret Coll Jordan Valley. Dept Water Ind Engr, Zemach, Israel.” Because of this, this article will be counted once in the search for graphene + Israel, which is a true positive, meaning Suckeveriene is truly affiliated with the country of Israel, and once in the search for graphene + Jordan, which, in this case, is a false positive, meaning Suckeveriene is not affiliated with the country of Jordan yet is represented in the results because of the ambiguous result hit for “Jordan”. As with the problem of duplication noted above, the occurrence of false positive is not typical and only appeared once in the first 100 records reviewed.

The remaining examination of results will focus exclusively on the data retrieved from the search in the Web of Science Core Collection that combines all of the graphene + [Country Name] searches into one. The results reported in this paper are based on data gathered on January 14th, 2015 and results were limited to items published prior to 2015. Since the earliest publication in the search results is from 1991, the data set covers the years 1991 through 2014.

## Authors and Country Affiliations

Since most articles in the search results were written by more than one author, the number of authors retrieved in the data search was 7,724. This number, however, should only be treated as an approximation since it does not take into account alternate spellings or misspellings of authors' names which would result in the appearance of two or more separate authors being counted for the same individual. So, while the author of this article presents the top Middle Eastern graphene authors in terms of publication output, she fully acknowledges that an error in indexing could easily change an author's ranking. Alternatively two authors with the same name could appear as a single author. While care was taken to manually check the top authors for this sort of over representation of output, or the under representation due to alternative spellings, the author of this article recognizes the possibility of this error.



Table B: Top 25 most prolific Middle Eastern graphene authors

Rank among Middle Eastern authors	Authors (Name as indexed)	Authors (Full names if available)	Number of publications in search results	Country affiliation
1	ASIRI AM	Asiri, Abdullah Mohamed	59	Saudi Arabia
2	SCHWINGENSCHLOGL U	Schwingschloegl, Udo	53	Saudi Arabia
	SUN XP	Sun, Xuping	51	China
3	CIRACI S	Ciraci, Salim	51	Turkey
4	ASGARI R	Asgari, Reza	48	Iran
5	AL-YOUBI AO	Al-Youbi, Abdulrahman O.	41	Saudi Arabia
5	AKHAVAN O	Akhavan, Omid	41	Iran
7	NEEK-AMAL M	Neek-Amal, Mehdi	40	Iran
	PEETERS FM	Peeters, Francois	38	Belgium
8	AHMADI MT	Ahmadi, Mohammad Taghi	33	Iran
9	ANSARI R	Ansari, R.	32	Iran
10	CHENG YC	Cheng, Yingchun	29	Saudi Arabia
	TIAN JQ	Tian, Jingqi	23	China
	LUO YL	Luo, Yonglan	23	China
	RAHMANI M	Rahmani, Meisa,	22	Malaysia
11	GHADERI E	Ghaderi, Elham	21	Iran
12	TOPSAKAL M	Topsakal, Mehmet	19	Turkey
12	SAHIN H	Sahin, Hasan	19	Turkey
12	KALONI TP	Kaloni, T. P.	19	Saudi Arabia
	QIN XY	Qin, Xiaoyun	18	China
15	POURFATH M	Pourfath, Mahdi	18	Iran
	POLINI M	Polini, Marco	18	Italy
15	KIANI MJ	Kiani, Mohammad Javad	18	Iran
15	FARAJPOUR A	Farajpour, Ali	18	Iran
18	ZAREYAN M	Zareyan, Malek	17	Iran
18	MOUSAVI H	Mousavi, Hamze	17	Iran
18	JELLAL A	Jellal, Ahmed	17	Saudi Arabia
	LU WB	Lu, Wenbo	16	China
21	JAFARI SA	Jafari, S. A.	16	Iran
21	ISMAIL R	Ismail, Razali	16	Iran
	MACDONALD AH	MacDonald, A. H.	15	USA
23	HOD O	Hod, Oded	15	Israel
23	HAN Y	Han, Yu	15	Saudi Arabia
23	ALSHAREEF HN	Alshareef, H. N.	15	Saudi Arabia

Table B represents the 25 most prolific graphene authors from the Middle East countries (as defined by this study). Papers published by these authors that were not indexed with graphene in

a topic field, and were perhaps on another topic, will not be represented in these results, and therefore the number reported above may not represent these authors' complete body of work. For comparative interest, authors who fall in this top 25 range who are affiliated with countries outside of the Middle East are also shown above. These authors are represented in the search results because they have co-authored papers with authors in the Middle East. It is particularly important to note that the number of publications retrieved in the search results for these authors are only those graphene publications with Middle Eastern collaborators, and this number may be highly inaccurate in representing these researchers' complete output in the field of graphene. Francois Peeters, for example, appeared in this author's original paper on graphene research trends in the top ten most published graphene authors among all countries; his article count reported at that time was 65 (Lehman 2011). The number 38 reported in Table B represents only the 38 papers prior to 2015 that he wrote in collaboration with an author (or multiple authors) who is affiliated with a country in the Middle East. Of the twenty-five most prolific Middle Eastern authors reported in this paper, thirteen are affiliated with Iran, eight with Saudi Arabia, three with Turkey, and one with Israel.

### Organization Affiliations

Another interesting factor to consider for the research reported here is with which institutions the authors' are affiliated. Over 1,500 different originations were retrieved in the search results. As noted with author's names being indexed inconstantly at times, the same problem exists for organization names. Again, the author of this paper has attempted to report as accurately as possible record counts for the various institutions by gathering differing representations of the same organization. For example, "INST RES FUNDAMENTAL SCI IPM" had 74 records, "INST STUDIES THEORET PHYS MATH IPM" had 16 records, "IPM" had 14 records, and "IPM TEHRAN" had one record. To the best of this author's knowledge, all these abbreviations represent the "Institute for Research in Fundamental Sciences" in Tehran, Iran and so are reported together in Table C, giving the Institute a record count of 105.

Table C: Top ten most prolific organizations

record count	Full Name	Country	Institution Type
181	Islamic Azad University [all campuses]	Iran	University
146	Sharif University of Technology	Iran	University
130	King Abdulaziz University	Saudi Arabia	University
130	King Abdullah University of Science and Technology	Saudi Arabia	University
105	Institute for Research in Fundamental Sciences	Iran	Research Institute
94	Bilkent University	Turkey	University
77	University of Tehran	Iran	University
59	Razi University	Iran	University
56	Chinese Academy of Sciences	China	Research Institute
54	Iran University of Science and Technology	Iran	University
51	Isfahan University of Technology	Iran	University

The most prolific organizations as presented above, not surprisingly mirror the country affiliations of the most prolific authors. Of the organizations presented in Table C, seven are located in Iran, two in Saudi Arabia, and one in Turkey. The Chinese Academy of Sciences in China is presented here as well for the reader's reference.

## Heavily Cited Papers

Understanding that citations of a work grow over time as more and more authors have the opportunity to look at and potentially reference that work, the top ten most cited papers as presented in Table D provide a single snapshot in time. These "Total Citations," like the other data used in this paper, are limited to citations prior to 2015.

Table D: Top ten most cited graphene papers with at least one Middle Eastern author

Total Citations	Title	Authors (Name as indexed)	Publication Year
750	Graphene/Polymer Nanocomposites	Kim, Hyunwoo; Abdala, Ahmed A.; Macosko, Christopher W.	2010
723	Chemical analysis of graphene oxide films after heat and chemical treatments by X-ray photoelectron and Micro-Raman spectroscopy	Yang, Dongxing; Velamakanni, Aruna; Bozoklu, Guelay; Park, Sungjin; Stoller, Meryl; Piner, Richard D.; Stankovich, Sasha; Jung, Inhwa; Field, Daniel A.; Ventrice, Carl A., Jr.; Ruoff, Rodney S.	2009
682	Observation of electron-hole puddles in graphene using a scanning single-electron transistor	Martin, J.; Akerman, N.; Ulbricht, G.; Lohmann, T.; Smet, J. H.; Von Klitzing, K.; Yacoby, A.	2008
493	Laser Scribing of High-Performance and Flexible Graphene-Based Electrochemical Capacitors	El-Kady, Maher F.; Strong, Veronica; Dubin, Sergey; Kaner, Richard B.	2012
488	Two- and One-Dimensional Honeycomb Structures of Silicon and Germanium	Cahangirov, S.; Topsakal, M.; Akturk, E.; Sahin, H.; Ciraci, S.	2009
402	Graphene oxide papers modified by divalent ions - Enhancing mechanical properties via chemical cross-linking	Park, Sungjin; Lee, Kyoung-Seok; Bozoklu, Gulay; Cai, Weiwei; Nguyen, SonBinh T.; Ruoff, Rodney S.	2008
320	Photocatalytic Reduction of Graphene Oxide Nanosheets on TiO <sub>2</sub> Thin Film for Photoinactivation of Bacteria in Solar Light Irradiation	Akhavan, O.; Ghaderi, E.	2009
268	Toxicity of Graphene and Graphene Oxide Nanowalls Against Bacteria	Akhavan, Omid; Ghaderi, Elham	2010
251	Probing the Electrochemical Properties of Graphene Nanosheets for Biosensing Applications	Alwarappan, Subbiah; Erdem, Arzum; Liu, Chang; Li, Chen-Zhong	2009
249	Graphene Nanomesh by ZnO Nanorod Photocatalysts	Akhavan, Omid	2010

It is interesting to note that five of the authors in Table D also appear in Table B, which shows the most prolific Middle Eastern graphene authors. Those authors are: Salim Ciraci of Turkey, Akhavan of Iran, Elham Ghaderi of Iran, Mehmet Topsakal of Turkey, and Hasan Sahin of Turkey. Topsakal, Sahin, and Ciraci, along with others, are coauthors on the fifth most cited graphene paper in this data set; Akhavan and Omid coauthored the seventh and eighth most cited papers. Akhavan was also sole author on the tenth most cited paper. Another author of note in the list of most cited papers is Gulay Bozoklu of Turkey, who appears twice on the list but not on the list of more prolific authors. Bozoklu is coauthor with many collaborators, all from the United States of America, on the secondmost cited paper. On the sixth most cited paper, Bozoklu's collaborators were from the United States of America, South Korea, and China. Thirty-nine unique authors representing nine countries appear on this "most cited" list. Focusing on the authors in the Middle East, seven are from Turkey, three from Israel, two from Iran, and one each from Egypt and United Arab Emirates.

The top most cited paper "Graphene/Polymer Nanocomposites" by Kim, Abdala, and Macosko written in 2010 is a review paper. Authors Kim and Macosko are affiliated with the United States of America and Abdala is from United Arab Emirates. Of the top ten most cited articles, eight report experimental results, and only one, "Two- and One-Dimensional Honeycomb Structures of Silicon and Germanium" is a theoretical paper (Cahangirov, Topsakal, Akturk, Sahin, and Ciraci 2009).

## Funding Agencies

Of course the research represented by the publications discussed in this paper could not happen without funding. About half (46.8%) of the publications in the search results did not have a funding agency listed in the database record but the majority do list their funding sources. When information on the funding agency is given, support usually came from two or more sources. Within publications listing funding sources, however, an agency's name often had many different ways of being indexed across the records. For example, the Scientific and Technological Research Council of Turkey (8 times) also appeared as "Tubitak" (41 times), "Scientific and Technological Research Council of Turkey Tubitak" (25 times), "Tubitak The Scientific and Technological Research Council of Turkey" (3 times) and so on. These differences even appear as misspellings or typos as in the case of one agency which is indexed with the spelling "poject" rather than "project" as part of its name. The author of this paper combined as many of these alternate spellings and name presentations as was possible in an effort to identify the 10 funding agencies that supported the largest number of publications. This list does not represent the top 10 in terms of the amount of funding provided, but rather reflects the relative number of publications that were produced as a result of the funding provided. It is important to remember, as mentioned above, that most publications listed two or more funding agencies.

Table E: Funding agencies supporting the research that led to publications

Funding Agency	Number of publications listing the agency as a source of funding
The Scientific and Technological Research Council of Turkey	97
National Natural Science Foundation of China	91
Iran Nanotechnology Initiative Council	70
National Science Foundation [United States of America]	58
National Basic Research Program of China	53
Israel Science Foundation	46
Turkish Academy of Sciences (TUBA)	42
Research Council of Sharif University of Technology [Iran]	38
Flemish Science Foundation (FWO-VI) [Belgium]	38
Iran National Science Foundation	37

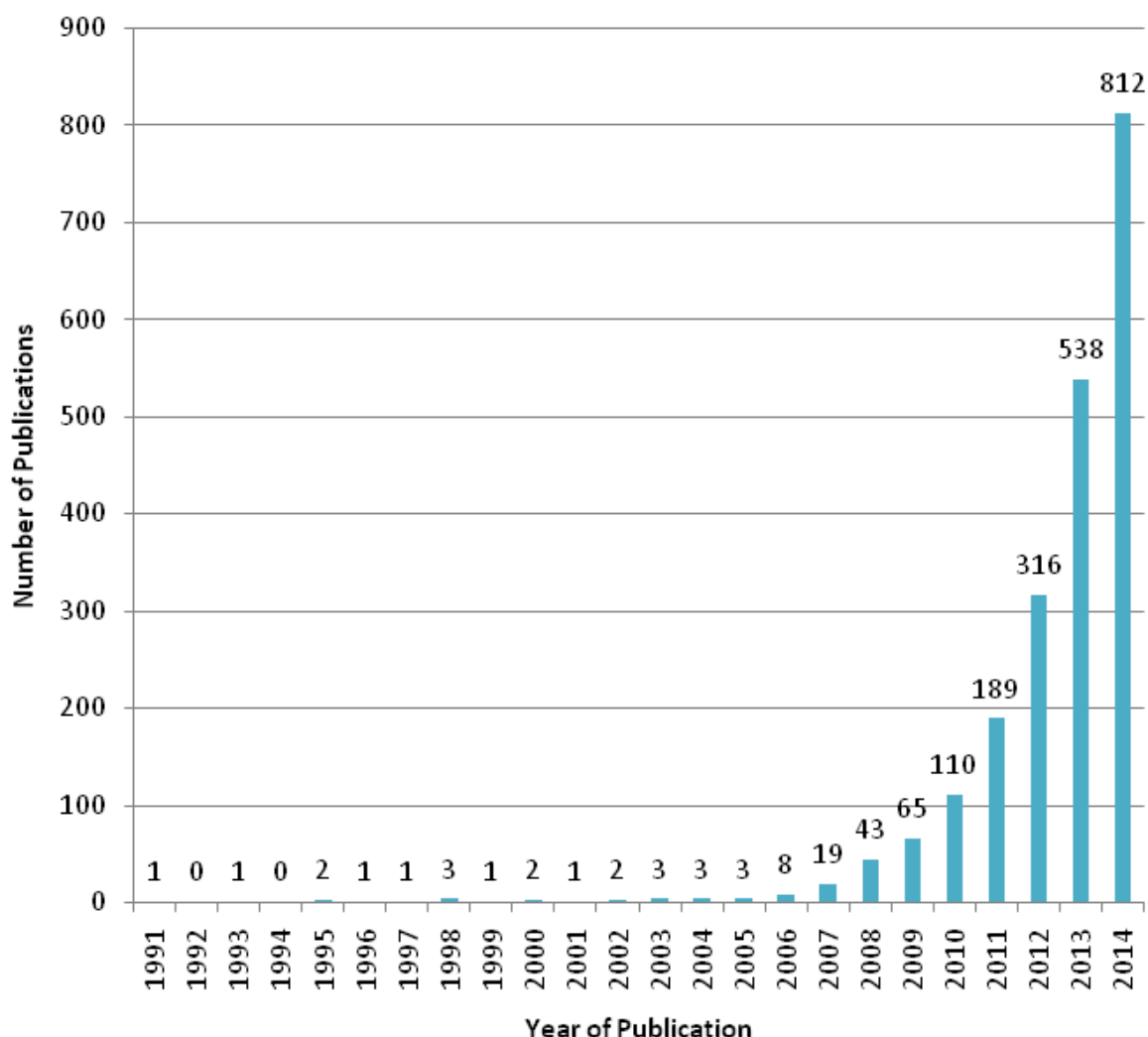
The top ten funding agencies whose support turned into the most number of publications are located in six different countries. In the Middle East, three of the funding agencies are in Iran, two are in Turkey, and one is in Israel. The other countries represented in Table E are China (two funding agencies), the United States of America (one), and Belgium (one).



### Graphene Research on the Rise

With graphene having only been positively isolated and identified in 2004, relatively speaking, the area of graphene research is fairly new. The table below presents the number of publications in the data set by publication year.

Table F: Number of graphene publications with at least one Middle Eastern author by year.



The oldest publication in the data set gathered here is the article “Effective and debye temperatures of alkali-metal atoms in graphite-intercalation compounds” by R. Moreh (Israel), N. Shnieg (Israel), and H. Zabel (United States of America) that appeared in *Physical Review B* in 1991. In their research they calculate the effective temperatures for atoms in a material sandwich that includes graphene layers. Their work considers graphene not as an isolated sheet, but as sheets in a greater material structure (Moreh, Shnieg, & Zabel 1991). Table F represents the 2,124 graphene publications from the Middle East that are analyzed throughout this paper. For comparison, a graphene as topic keyword search for publications prior to 2015 within the Core Collection but without regional limits retrieves 54,742 publications. The trend in growth of graphene research worldwide is very similar to what is shown in Table F. In both cases the large majority of the publications have been produced since 2010, which was the year of the graphene Nobel Prize. In the case of the worldwide publication data set, over 88% of the publications are from 2010-2014. For the Middle Eastern publications, over 92% are from the same years.



## Top Journals

The majority (nearly 95%) of the results retrieved are indexed as articles, rather than other document types such as proceedings papers (3%), and were published in over 450 sources. The top ten journals determined by the number of articles they published in the data set are presented below.

Table G: Most popular journal outlets for Middle Eastern graphene authors

Journal Title	Number of articles
Physical Review B	184
RSC Advances	64
Physica E: Low Dimensional Systems and Nanostructures	64
Journal of Applied Physics	60
Applied Physics Letters	56
Solid State Communications	42
Journal of Physical Chemistry C	37
ACS Nano	36
Electrochimica Acta	33
Carbon	32

While Physical Review B is clearly the top journal for hosting graphene articles with authors from Middle Eastern countries, the research appears in a wide array of journals. Looking at the indexed research areas for these articles is also interesting. Most of the articles (99%) are indexed with one or more associated research areas. As the reader might expect, the most frequently associated areas were: physics (49%), chemistry (33%), and materials science (29%). Many articles were also indexed with the research area of “science technology and other topics” (20%). Thirty-three other topics were used to describe the published research.

## Conclusion

The primary searches of graphene + [Country Name] that framed this article revealed Iran as the most productive Middle Eastern country in terms of graphene research publications. It makes sense then, that Iranian authors appear on the most prolific author list (thirteen out of twenty-five authors) and on the most cited papers list (two authors on three out of ten papers). The lists of funding agencies and supporting organizations also reveal strong support for graphene research from within the country. Saudi Arabia and Turkey are also countries with authors making significant contributions to graphene research. Eight of the twenty-five most prolific authors are affiliated with Saudi Arabia. Of the thirty-nine authors represented on the most cited graphene papers, seven are from Turkey. Overall, this study reveals that as graphene research output grows worldwide, researchers in the Middle East are keeping pace and adding substantially to the growing understanding of this highly important material.

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