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Computing Y-index of Different Corona Products of Graphs

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

The Y-index of a graph is defined by the sum of four of degrees of the vertices of a graph. Among the all topological indices the Zagreb indices have been used more considerably than any other topological indices in chemical literature. The concept of Corona Product is a recent inclusion to mathematical vocabulary. One of the most significant graph operations is the corona product of several generic and specific graphs, which is one of the most well-known graph products. In this study, we derive some explicit formulations of several corona product types, including subdivision-vertex corona, subdivision-edge corona, subdivision-vertex neighborhood corona, subdivision-edge neighborhood corona, and vertex-edge corona of two graphs.

Keywords: Topological index; Zagreb index; Y-index; corona product; graph operations.

1 Introduction

The definition of a topological function is a real valued function that converts any molecular graph into a real number and is inescapably invariant under graph automorphism. In theoretical chemistry, [1,2,3,4,5], molecule structure is given a numerical value that closely corresponds to the physical quantities and activities. For

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modeling the physicochemical, pharmacologic, toxicologic, biological, and other aspects of chemical substances, topological indices, also known as molecular structure descriptors, are used.

In this paper, we consider only finite, connected and undirected graphs without any self-loops or multiple edges. Let A be a graph with vertex set V(A) and edge set E(A). So that the vertex set will be considered n and the edge set will be considered m. The vertices u and v is connected by edge and is denoted by u v. Let $d_G(v)$ denote the degree of the vertex v in A, which is the number of edges incident to v.

Zagreb indices are among the best applications for recognizing physical properties and chemical reactions in practical applications. The First Zagreb index $M_1(A)$ and Second Zagreb index $M_2(A)$ were firstly considered by I. Gutman and N. Trinajstic in 1972 [6] defined as

$$M_1(A) = \sum_{v \in V(A)} d_A(u)^2 = \sum_{uv \in E(A)} [d_A(u) + d_A(v)]$$

$$M_2(A) = \sum_{u,v \in V(A)} d_A(u)\ d_A(v)$$

These indices have considerably studied with respect to both mathematical and chemical point of view. In 2005, Li and Zheng [6], introduce the First general Zagreb index as

$$M_1^{\alpha+1}(A) = \sum d_A{}^{\alpha+1} d_A(v)$$
$$= \sum_{uv \in E(A)} d_A^{\alpha}(u) + d_A^{\alpha}(v)$$

In 2018, Nilanjan De uses modern index to calculate the F-index and co index of some derived graphs [7,8]. Its special of First general Zagreb index where $\alpha = 3$

$$M_1^4(A) = \sum_{uv \in E(A)} d_A^3(u) + d_A^3(v)$$

So that the Y-index is defined as [9],

$$Y(A) = \sum_{u \in V(A)} d_A^4(u) = \sum_{uv \in E(A)} d_A^3(u) + d_A^3(v)$$

Let A_1 and A_2 be two simple connected graphs with n_i number of vertices and m_i number of edges respectively, for $i \in \{1,2\}$. [8] The Corona product $A_1 \circ A_2$ of these two graphs is obtained by taking one copy of A_1 and n_1 copies of A_2: and by joining each vertex of the i-th copy of A_2 to the i-th vertex of A_1 where $1 \le i \le n$. The corona product of A_1 and A_2 has total number of $(n_1 n_2 + n_1)$ vertices and $(m_1 + n_1 m_2 + n_1 n_2)$ edges.

The Subdivision graph S=S(A) is a graph obtained from A by replacing each of its edges by a path of length two, or equivalently by inserting an additional vertex into each edge of A.

2 Main Results

2.1 Subdivision-vertex corona

Definition: [10] Let A_1 and A_2 be two vertex disjoint graphs . The Subdivision-vertex corona of A_1 and A_2 is denoted by $A_1 \boxdot A_2$ and obtained from S(A_1) and n_1 copies of A_2 , all vertex-disjoint, by joining the $i-th$ vertex of V(A_1) to every vertex in the $i-th$ copy of A_2

By definition it is clear that the Subdivision –vertex corona $A_1 \boxdot A_2$ has $n_1(1+n_2)+m_1$ vertices and $2m_1+n_1(n_2+m_2)$ edges. Also the degree of the vertices of $A_1 \boxdot A_2$ are given by

$$d_{A_1 \boxdot A_2}(v_i) = d_{A_1}(v_i) + n_2 \qquad for\ \ i = 1,2,...n_1$$
$$d_{A_1 \boxdot A_2}(e_i) = 2 \qquad for\ i = 1,2,...m_1$$
$$d_{A_1 \boxdot A_2}(v_j^i) = d_{A_2}(u_j) + 1 \qquad for\ \ i = 1,2,.....n_1 and \quad j = 1,2,....n_2$$

We calculate the Y-index for the Subdivision-vertex corona $A_1 \boxdot A_2$.

Theorem 2.1: The Y-index of the Subdivision- vertex corona $A_1 \boxdot A_2$ is given by

$$Y(A_1 \boxdot A_2) = Y(A_1) + 4n_2F(A_1) + 6{n_2}^2M_1(A_1) + 8m_1{n_2}^3 + n_1{n_2}^4 + 16m_1 + n_1\ Y(A_2) + 4n_1\ \mathrm{F}(A_2) + 6n_1M_1(A_2) + 8n_1m_2 + n_1n_2$$

Proof : From the definition of Subdivision-vertex corona $A_1 \boxdot A_2$, we get

$$Y(A_1 \boxdot A_2) = \sum_{i=1}^{n_1} (d_{A_1}(v_i)+n_2)^4 + \sum_{i=1}^{m_1} 2^4 + \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} (d_{A_2}(u_j)+1)^4$$

$$= \sum_{i=1}^{n_1} d_{A_1}(v_i)^4 + 4n_2 d_{A_1}(v_i)^3 + 6d_{A_1}(v_i)^2 {n_2}^2 + 4d_{A_1}(v_i){n_2}^3 + n_2^4 +$$

$$16m_1 + n_1(\sum_{j=1}^{n_2} d_{a_2}(u_j)^4 + 4d_{A_2}(u_j)^3 + 6d_{A_2}(u_j) + 4d_{A_2}(u_j) + 1)$$

$$= Y(A_1) + 4n_2F(A_1) + 6{n_2}^2M_1(A_1) + 8m_1{n_2}^3 + n_1{n_2}^4$$
$$+16m_1 + n_1\ Y(A_2) + 4n_1\ \mathrm{F}(A_2) + 6n_1M_1(A_2) + 8n_1m_2 + n_1n_2$$

Hence, we get the desired result.

Corollary. 2.2

$$Y(P_n \boxdot P_m) = nm^4 + 8m^3(n-1) + 12m^2(2n-3) + 113nm - 56m - 98n - 46$$
$$Y(C_n \boxdot C_m) = nm^4 + 8nm^3 + 24nm^2 + 113nm + 32n$$
$$Y(C_n \boxdot P_m) = nm^4 + 8nm^3 + 24nm^2 + 113nm - 98n$$

The Subdivision-vertex corona of $P_4, P_2\ and\ C_3$ is given by

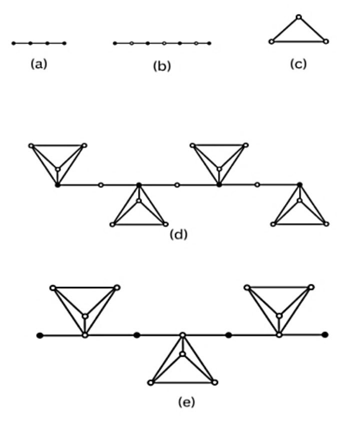


Fig. 1. (a)-path p4, (b)-Subdivision S (p4), (c)-Cycle c3, (d)-Subdivision –vertex corona p4 c3, (e)-Subdivision-edge corona p4 c3

2.2 Subdivision-edge corona

Definition. [10] Again from the definition of subdivision graphs, The Subdivision-edge corona product $A_1 \oplus A_2$ of $A_1$and A_2 is obtained from the $S(A_1)$ and m_1 copies of A_2 such that for all disjoint vertices joining the i-th vertex of $S(A_1)$ to every vertex in the i-th copy of A_2. Clearly the product $A_1 \oplus A_2$ has $m_1(1+n_2)+n_1$ vertices and $m_1(n_2+m_2+2)$ edges. Also the degree of vertices of $A_1 \oplus A_2$ are given by

$$d_{A_1 \oplus A_2}(v_i) = d_{A_1}(v_i) \qquad for\ i = 1,2,...n_1$$
$$d_{A_1 \oplus A_2}(v_i) = 2 + n_2 \qquad for\ i = 1,2,...m_1$$
$$d_{A_1 \oplus A_2}(v_j^i) = d_{A_2}(u_j) + 1 \qquad for\ i = 1,2,.....n_1 and \quad j = 1,2,....n_2$$

Theorem 2.3: The Y-index of Subdivision-edge corona $A_1 \oplus A_2$ is given by

$$Y(A_1 \oplus A_2) = Y(A_1) + [m_1\ (n_2+2)]^4 + m_1 Y(A_2) + 4m_1\ F(A_2) + 6m_1 M_1(A_2)\ + 8m_1 m_2 + m_1 n_2$$

Proof: From the definition of Subdivision-edge corona $A_1 \oplus A_2$, we have

$$Y(A_1 \oplus A_2) = \sum_{i=1}^{n_1} (d_{A_1}(v_i))^4 + \sum_{i=1}^{m_1} (2+n_2)^4 + \sum_{i=1}^{m_1} \sum_{j=1}^{n_2} (d_{A_2}(u_j)+1)^4$$
$$= Y(A_1) + [m_1\ (n_2+2)]^4 + m_1 Y(A_2) + 4m_1\ F(A_2) + 6m_1 M_1(A_2)\ + 8m_1 m_2 + m_1 n_2$$

Hence we get the result

Corollary.2.4

$$Y(P_n \oplus P_m) = m^4(n-1) + 8m^3(n-1) + 2m^2(n-1) + 113nm - 113m - 98n + 84$$
$$Y(C_n \oplus C_m) = nm^4 + 8nm^3 + 2nm^2 + 113nm + 32n$$
$$Y(C_n \oplus P_m) = nm^4 + 8nm^3 + 2nm^2 + 113nm - 98n$$

2.3 Subdivision- vertex neighborhood corona

Definition. [11] Subdivision –vertex neighborhood corona product $A_1 \odot A_2$ of A_1 and A_2 is obtained from the $S(A_1)$ and $n_1$copies of A_2 such that for all disjoint vertices joining the neighbors of the i-th vertex of $S(A_1)$ to every vertex in the i-th copy of A_2. Thus $A_1 \odot A_2$ has $m_1(1+n_2)+n_1$ vertices $2m_1$ edges .

Let $V(A_1) = \{v_1, v_2, ... v_{n_1}\}, I(A_1) = \{e_1, e_2, ... e_{m_1}\}$ and $V(A_2) = \{v_1, v_2, ... v_{n_2}\}$. Also , let the vertex set of the i-th copy of A_2 is denoted by $V(A_2^i) = \{u_1^i, u_2^i, ... u_{n_2}^i\}$, for i=1,2,.., n_2. Then $(A_1 \odot A_2) = V(A_1) \cup I(A_1) \cup [V^1(A_2) \cup V^2(A_2) \cup ... \cup V^{n_1}(A_2)]$. The degree of the vertices of $A_1 \odot A_2$ are given by

$$d_{A_1 \odot A_2}(v_i) = d_{A_1}(v_i) \qquad for\ i = 1,2,...n_1$$
$$d_{A_1 \odot A_2}(e_i) = 2n_2 + 2 \qquad for\ i = 1,2,...m_1$$
$$d_{A_1 \odot A_2}(v_j^i) = d_{A_2}(u_j) + d_{A_1}(v_j) \qquad for\ i = 1,2,.....n_1 and \quad j = 1,2,....n_2$$

The Y-index of Subdivision-vertex neighborhood corona of two graphs is defined in the following theorem

Theorem 2.5: The Y-index of $A_1 \odot A_2$ is given by

$$Y(A_1 \odot A_2) = Y(A_1) + 16m_1(n_2+1)^4 + n_1 Y(A_2) + 8m_1\ F(A_2)$$
$$+6M_1(A_2)\ M_1(A_1) + 8m_2 F(A_1) + n_2 Y(A_1)$$

Proof: From the definition of $A_1 \odot A_2$, we have

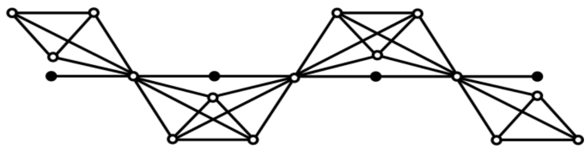
$$Y(A_1 \odot A_2)= \sum_{i=1}^{n_1} (d_{A_1}(v_i)^4 + \sum_{i=1}^{m_1} (2n_2+2)^4 + \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} (d_{A_2}(u_j) + (d_{A_2}(v_j))^4$$
$$= Y(A_1) + 16m_1(n_2+1)^4 + n_1 Y(A_2) + 8m_1 F(A_2)$$
$$+6M_1(A_2)\, M_1(A_1) + 8m_2 F(A_1) + n_2 Y(A_1)$$

Hence we get the desired result

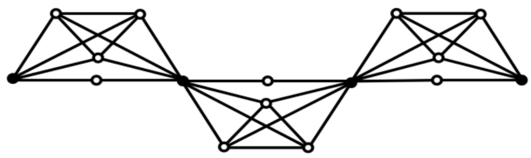
Corollary. 2.6

$$Y(P_n \odot P_m)= 16m^4(n-1) + 64m^3(n-1) + 96m^2(n-1) + 320nm - 414m - 318n + 394$$
$$Y(C_n \odot C_m)= 16nm^4 + 6nm^3 + 96nm^2 + 320nm + 32n$$
$$Y(C_n \odot P_m)= 16nm^4 + 64nm^3 + 96nm^2 + 320nm - 318n$$

The Subdivision-vertex neighborhood corona of P_4, P_2 *and* C_3 is given in the figure.



(f)



(g)

Fig. 2. (f)- Subdivision-vertex neighborhood corona p4 c3, (g)- Subdivision-edge neighborhood corona p4 c3

2.4 Subdivision-edge neighborhood corona

Definition. [11]: For two vertex disjoint graphs $A_1$and A_2, the Subdivision –edge neighborhood corona $A_1$and A_2 is denoted by $A_1 \boxminus A_2$ and obtained from $S(A_1)$ and n_1 copies of A_2 all vertex disjoint, by joining the neighbors of the i-th vertex of $V(A_1)$ to every vertex in the i-th copy of A_2.

Let $V(A_1) = \{v_1, v_2, \dots v_{n_1}\}, I(A_1) = \{e_1, e_2, \dots e_{m_1}\}$ and $V(A_2) = \{v_1, v_2, \dots v_{n_2}\}$. Also , let the vertex set of the i-th copy of A_2 is denoted by $V(A_2^i) = \{u_1^i, u_2^i, \dots u_{n_2}^i\}$, for i=1,2,.., n_1. Then $A_1 \boxminus A_2 = V(A_1) \cup I(A_1) \cup [V^1(A_2) \cup V^2(A_2) \cup \dots \cup V^{n_1}(A_2)]$. The degree of the vertices of $A_1 \boxminus A_2$ are given by

$$d_{A_1 \boxminus A_2}(v_i) = (n_2+1)d_{A_1}(v_i) \qquad for\ i = 1,2,\dots n_1$$
$$d_{A_1 \boxminus A_2}(e_i) = 2 \qquad for\ i = 1,2,\dots m_1$$
$$d_{A_1 \boxminus A_2}(v_j^i) = d_{A_2}(u_j) + 2 \qquad for\ i = 1,2,\dots.n_1\ \ and\ \ j = 1,2,\dots.n_2$$

The Subdivision-edge neighborhood corona of P_4, P_2 *and* C_3 is given in the Fig. 2.
So the result of this section is the following

Theorem.2.7

The Y-index of $A_1 \boxminus A_2$ is given by

$$Y(A_1 \boxminus A_2)=Y(A_1)(n_2+1)^4+16m_1+n_1Y(A_2)+8n_1\,F(A_2)$$
$$+24n_1M_1(A_2)\ +64n_1m_2+16n_1n_2$$

Proof: From the definition of Subdivision –edge neighborhood corona product of two graphs. We have

$$Y(A_1 \boxminus A_2) = \sum_{i=1}^{n_1}(n_2+1)^4(d_{A_1}(v_i)^4+\sum_{i=1}^{m_1}2^4+\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}(d_{A_2}(u_j)+2)^4$$

$$= (n_2+1)^4Y(A_1)+16m_1+n_1(\sum_{i=1}^{n_2}d_{A_2}(u_j)^4+8d_{A_2}(u_j)^3$$
$$+24d_{A_2}(u_j)^2+4d_{A_2}(u_j).2^3+2^4)$$
$$= Y(A_1)(n_2+1)^4+16m_1+n_1Y(A_2)+8n_1\,F(A_2)$$
$$+24n_1M_1(A_2)\ +64n_1m_2+16n_1n_2$$

Hence we get the result

Corollary. 2.8

$$Y(P_n \boxminus P_m\ ) = 16nm^4-30m^4+64nm^3-120m^3+96nm^2-180m^2+320nm-318n-120m-46$$
$$Y(C_n \boxminus C_m) = 16nm^4+64nm^3+96nm^2+320nm+32n$$
$$Y(C_n \boxminus P_m\ ) = 16nm^4+64nm^3+96nm^2+320nm-318n$$

2.5 The Vertex –edge corona

Definition: [12] The vertex –edge corona of two graphs A_1 and A_2 is denoted by $A_1 \boxtimes A_2$ is the graph obtained by taking one copy of A_1, $n_1$copies of A_2 and also $m_1$copies of A_2, then joining the i-th vertex of $A_1$to every vertex in the i-th vertex copy of A_2 and also joining the end vertices of j-th edge of A_1 to every vertex in the j-th edge copy of A_2.

Let the vertex set of the j-th edge copy of A_2 is denoted by $V_{\ je}(A_2)=\{u_{ji},u_{j2},\dots u_{jn_2}\}$ and the vertex set of the i-th vertex copy of A_2 is denoted by $V_{iv}(A_2)=\{w_{i1},w_{i2},\dots w_{in}\}$. Also let us denote the edge set of the j-th edge and i-th vertex copy of A_2 by $E_{je}(A_2)$ and $E_{iv}(A_2)$ respectively. According to this definition we have the vertex –edge corona $A_1 \boxtimes A_2$ has $m_1+m_1(m_2+2m_2)+n_1n_2+n_1m_2$ edges and $n_1+n_1n_2+mn_2$ vertices . Also the degree of the vertices of $A_1 \boxtimes A_2$ are given by

$$d_{A_1 \boxtimes A_2}(v_i)=(n_2+1)d_{A_1}(v_i)+n_2 \qquad \forall\ v_i \in V(A_1)$$
$$d_{A_1 \boxtimes A_2}(e_i)=d_{A_2}(u_j)+2 \qquad \forall\ u_{ij} \in V_{ie}(A_2)$$
$$d_{A_1 \boxtimes A_2}(v_j^i)=d_{A_2}(w_j)+1 \qquad \forall\ w_{ij} \in V_{ie}(A_2)$$

Theorem.2.9

The Y-index of $A_1 \boxtimes A_2$ is given by

$$Y(A_1 \boxtimes A_2)=Y(A_1)(n_2+1)^4+4(n_2+1)^3Y(A_1)n_2+6{n_2}^2(n_2+1)^2M_1(A_1)+8m_1(n_2+1)$$
$${n_2}^3+n_1{n_2}^4+m_1Y(A_2)+8m_1F(A_2)+24M_1(A_2)m_1+8n_1m_2+n_1n_2$$

Proof: From the definition of vertex-edge corona of graphs, we have

$$Y(A_1 \boxtimes A_2) = \sum_{v_i \in V(A_1)} d_A(v_i)^4 + \sum_{e_i \in E(A_1)} \sum_{u_{ij} \in V(A_2)} d_A(u_{ij})^4 + \sum_{v_i \in V(A_1)} \sum_{w_{ij} \in V(A_2)} d_A(w_{ij})^4$$
$$= S_1 + S_2 + S_3 \text{(say)}$$

We have now determined by calculating S_1's contribution

$$S_1 = \sum_{v_i \in V(A_1)} d_A(v_i)^4$$
$$= \sum_{v_i \in V(A_1)} [(n_2+1)d_{A_1}(v_i) + n_2]^4$$
$$= (n_2+1)^4 Y(A_1) + 4(n_2+1)^3 F(A_1) n_2 + 6(n_2+1)^2 M_1(A_1) n_2^2 + 8(n_2+1) m_1 n_2^3 + n_1 n_2^4 \quad (1)$$

Also, we have the contribution of S_2 as

$$S_2 = \sum_{e_i \in E(A_1)} \sum_{u_{ij} \in V(A_2)} d_A(u_{ij})^4$$
$$= \sum_{e_i \in E(A_1)} \sum_{u_{ij} \in V(A_2)} [d_{A_2}(u_j) + 2]^4$$
$$= = m_1 Y(A_2) + m_1 8F(A_2) + 24 m_1 M_1(A_2) + 64 m_1 m_2 + 16 m_1 n_2\text{-} \quad (2)$$

Similarly, we get the S_3' s contribution

$$S_3 = \sum_{v_i \in V(A_1)} \sum_{w_{ij} \in V(A_2)} d_A(w_{ij})^4$$
$$= \sum_{v_i \in V(A_1)} \sum_{w_{ij} \in V(A_2)} [d_{A_2}(w_j) + 1]^4$$
$$= n_1 Y(A_2) + n_1 4F(A_2) + 6 n_1 M_1(A_2) + 8 n_1 m_2 + n_1 n_2 \quad (3)$$

After adding (1),(2) and (3) we obtain the equality in the statement of the theorem as required

Corollary. 2.10
$Y(P_n \boxtimes P_m) = 81nm^4 - 130m^4 + 216nm^3 - 368m^3 + 216nm^2 - 384m^2 + 433nm - 432m - 480n + 336$
$Y(C_n \boxtimes C_m) = 81nm^4 + 216nm^3 + 216nm^2 + 465nm + 16n$
$Y(C_n \boxtimes P_m) = 81nm^4 + 216nm^3 + 216nm^2 + 465nm - 464n$

3 Conclusion

The corona product can be used to improve the latest scientific advancements, like the Internet of Things, Virtual Reality, and Augmented Reality, among others. Corona Product is so crucial to our inquiry. The Y-index of various corona products, including subdivision-vertex corona, subdivision-edge corona, subdivision-vertex neighborhood corona, subdivision-edge neighborhood corona, and vertex-edge corona, are computed in this article. As a practical example, we develop some explicit corona product formulas for specific graphs.

Competing Interests

Authors have declared that no competing interests exist.

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