

$(r)$ -Pancyclic,  $(r)$ -Bipancyclic and Oddly  
 $(r)$ -Bipancyclic Graphs\*

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**Abstract**

A graph with  $v$  vertices is  $(r)$ -pancyclic if it contains precisely  $r$  cycles of every length from 3 to  $v$ . A bipartite graph with even number of vertices  $v$  is said to be  $(r)$ -bipancyclic if it contains precisely  $r$  cycles of each even length from 4 to  $v$ . A bipartite graph with odd number of vertices  $v$  and minimum degree at least 2 is said to be oddly  $(r)$ -bipancyclic if it contains precisely  $r$  cycles of each even length from

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\*Research supported by NSF REU Grant DMS1262838, University of West Georgia

4 to  $v - 1$ . In this paper, using computer search, we classify all  $(r)$ -pancyclic and  $(r)$ -bipancyclic graphs with  $v$  vertices and at most  $v + 5$  edges. We also classify all oddly  $(r)$ -bipancyclic graphs with  $v$  vertices and at most  $v + 4$  edges.

**Keywords:** pancyclic, bipancyclic,  $(r)$ -pancyclic,  $(r)$ -bipancyclic, oddly  $(r)$ -bipancyclic

## 1 Definitions

All graphs in this paper are finite, simple and undirected. A *pancyclic* graph, see [1], of order  $v$  is a graph that contains cycles of every length from 3 to  $v$ . Pancyclic graphs are a generalization of Hamiltonian graphs, which have a cycle containing all the vertices of the graph. A pancyclic graph with exactly one cycle of every possible length is called *uniquely pancyclic* (UPC) (see [4, 3]).

A bipartite graph on  $v$  vertices,  $v$  even, is called a *uniquely bipancyclic* (UBPC) if it contains precisely one cycle of every even length from 4 to  $v$ .

The definitions above can be generalized as follows. A graph with  $v$  vertices is  *$(r)$ -pancyclic* [6] if it contains precisely  $r$  cycles of every length from 3 to  $v$ . Similarly, a bipartite graph with even number of vertices  $v$  is said to be  *$(r)$ -bipancyclic* if it contains precisely  $r$  cycles of each even length from 4 to  $v$ .

A bipartite graph with odd number of vertices  $v$  cannot have a cycle of length  $v$  and the largest possible cycle length in such graphs is  $v - 1$ . On the other hand, adding a pendant edge to a graph does not change the cycle structure of that graph. This brings us to the following definition. A bipartite graph with odd number of vertices  $v$  and minimum degree at least 2 is said to be *oddly  $(r)$ -bipancyclic* if it contains precisely  $r$  cycles of each even length from 4 to  $v - 1$ .

Every  $(r)$ -pancyclic or  $(r)$ -bipancyclic graph is Hamiltonian, so we shall represent a  $v$ -vertex  $(r)$ -pancyclic or  $(r)$ -bipancyclic graph as a Hamilton cycle together with some edges, which we shall call *chords*. Similarly, a  $v$ -vertex oddly  $(r)$ -bipancyclic graph is represented as a cycle  $C$  of length  $v - 1$  together with some edges, which are either chords or are edges at the vertex  $u \notin V(C)$ , which we shall call *chordettes*.

In this paper, using computer search, we classify all  $(r)$ -pancyclic and  $(r)$ -bipancyclic graphs with  $v$  vertices and at most  $v + 5$  edges. We also classify all oddly  $(r)$ -bipancyclic graphs with  $v$  vertices and at most  $v + 4$  edges.

## 2 Computer search

The new result presented in the following sections obtained using different computer programs. The codes for these programs can be found at <https://github.com/osawin/Pancyclic>. Each of these programs accepts as input a text file containing a positive integer to determine the number of cycles of each length and a list of graph schema. Each schema has a name, and a list of arcs and chords, both represented by a pair of integers denoting their adjacent vertices. The program goes through the schema one by one looking for valid graphs. First, the program determines which edges are arcs, and which are chords or chordettes, based on the formatting of the input. Then, the program finds all cycles within the schema. Next, the program assigns each arc a variable, representing the size of the path it will be replaced with to generate a graph. The program tests all possible combinations of values of these variables to see if it will generate a valid graph. In order to search through graphs faster, the program tests some classes of combinations of arc lengths. For example, the code assigns all possible combinations of even or odd to arcs, and examines which combinations will result in a valid number of even and odd cycle lengths. This allows the code to quickly pass over many non-valid graphs. Once the program has found all valid graphs, it outputs a description of the schema it was checking, whether that layout contains any valid graphs, and the arc lengths that generates valid graphs, if any is found.

## 3 $(r)$ -pancyclic graphs

In [4], Shi classifies all the the UPC graphs with  $v$  vertices and  $v + m$  edges for  $m = 0, 1, 2, 3$  (see Figure 1) and conjectures that:

**Conjecture 3.1.** *There is no UPC graph with  $v$  vertices and  $v + m$  edges for  $m \geq 4$ .*

In [3], using computer programs, Markström reconfirms the results obtained by Shi in [4] and shows that there is no UPC graph with  $v$  vertices and  $v + 5$  edges.

In [6], Zamfirescu studies (2)-pancyclic graphs and finds the two (2)-pancyclic graphs of order 8, which are the smallest (2)-pancyclic graphs. In the same paper, he proves that there exist no (2)-pancyclic graphs on 9 or 10 vertices. For each  $v \in \{11, 13, 17, 19\}$  a (2)-pancyclic graph of order  $v$  is also presented in [6]. (See Figure 2.)

Computer search shows that:

**Theorem 3.2.** *Let  $G$  be a graph with  $v$  vertices and  $v + m$  edges, where  $0 \leq m \leq 5$ .*

1. The graphs displayed in Figure 3 are the only (2)-pancyclic graphs with  $v$  vertices and  $v + m$  edges, where  $0 \leq m \leq 5$ .
2. There is no ( $r$ )-pancyclic graph,  $r \geq 3$ , with  $v$  vertices and  $v + m$  edges, where  $0 \leq m \leq 5$ .

## 4 ( $r$ )-bipancyclic graphs

Wallis [5] finds all uniquely bipancyclic graphs on at most 30 vertices. These graphs are displayed in Figure 4. In [2], using computer programs, khodkar et al. show that (see Figure 5):

1. If  $32 \leq v \leq 56$ , and  $v \neq 44$ , then there are no UBPC graphs of order  $v$ ;
2. There are precisely six non-isomorphic UBPC graphs of order 44 (see Figure 5);
3. There are no other UBPC graphs with  $v$  vertices and  $v + m$  edges for  $0 \leq m \leq 5$ .

Using computer search we obtain:

- Theorem 4.1.** *1. The graphs displayed in Figure 6 are the only (2)-bipancyclic graphs with  $v$  vertices and  $v + m$  edges, where  $0 \leq m \leq 5$ .*
2. There is no ( $r$ )-bipancyclic graph,  $r \geq 3$ , with  $v$  vertices and  $v + m$  edges, where  $0 \leq m \leq 5$ .

## 5 Oddly ( $r$ )-bipancyclic graphs

In this section we initiate the study of oddly ( $r$ )-bipancyclic graphs. These are the bipartite graphs with odd number of vertices  $v$  and minimum degree at least 2 which have precisely  $r$  cycles of every even length from 4 to  $v - 1$ .

Our computer search shows that:

**Theorem 5.1.** *The graphs displayed in Figures 7, 8, 9 and 10 are the only oddly ( $r$ )-bipancyclic graphs with  $v$  vertices and  $(v - 1) + m$  edges, where  $2 \leq m \leq 5$  and  $r \geq 1$ .*

**Acknowledgement:** The authors would like to thank Alexander Clifton for his suggestion to study oddly ( $r$ )-bipancyclic graphs.

## References

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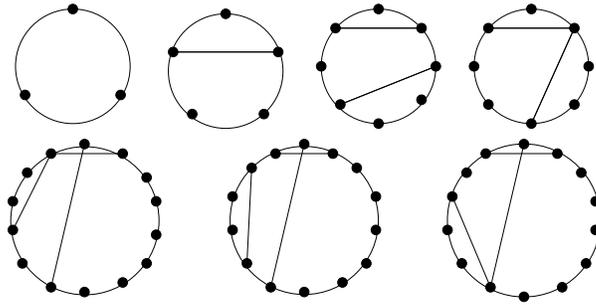


Figure 1: The (1)-pancyclic graphs with three or fewer chords

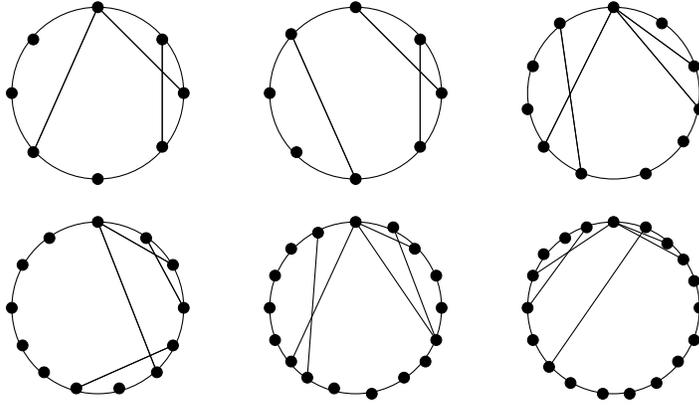


Figure 2: The (2)-pancyclic graphs given in [6],  $v = 8, 11, 13, 17, 19$

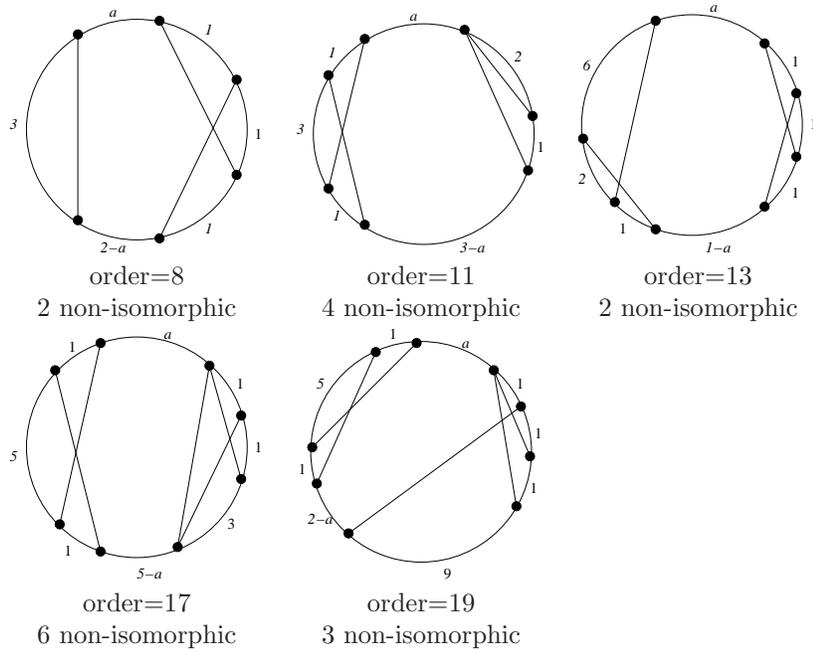


Figure 3: The (2)-pancyclic graphs with five chords or less. The label for an arc indicates the number of edges on that arc.

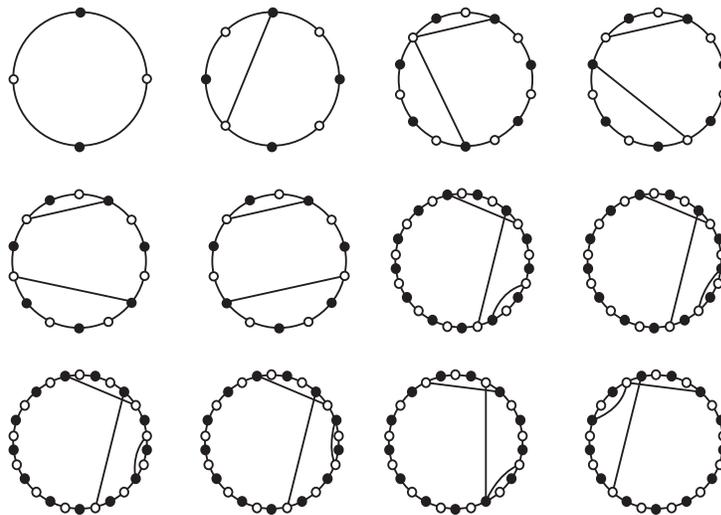


Figure 4: The (1)-bipancyclic graphs of order less than 32

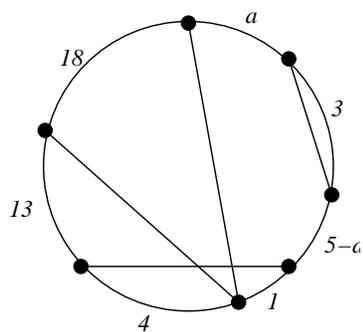


Figure 5: The six non-isomorphic (1)-bipancyclic graphs of order 44

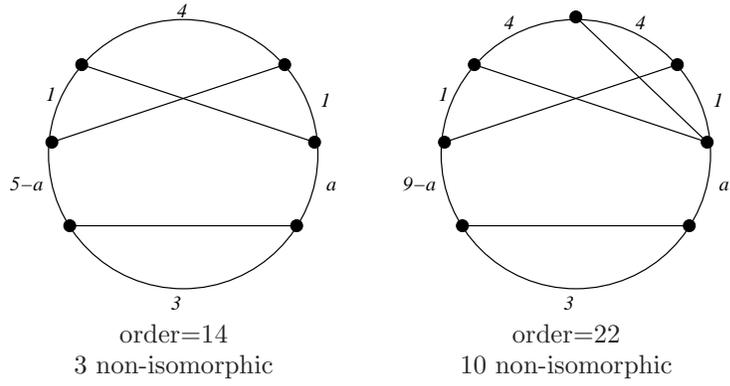


Figure 6: The (2)-bipancyclic graphs with at most four chords

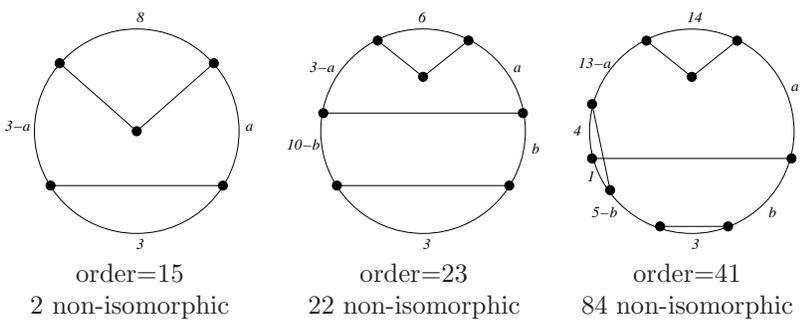


Figure 7: The oddly (1)-bipancyclic graphs with  $v$  vertices and  $(v - 1) + m$  edges, where  $m \leq 5$ .

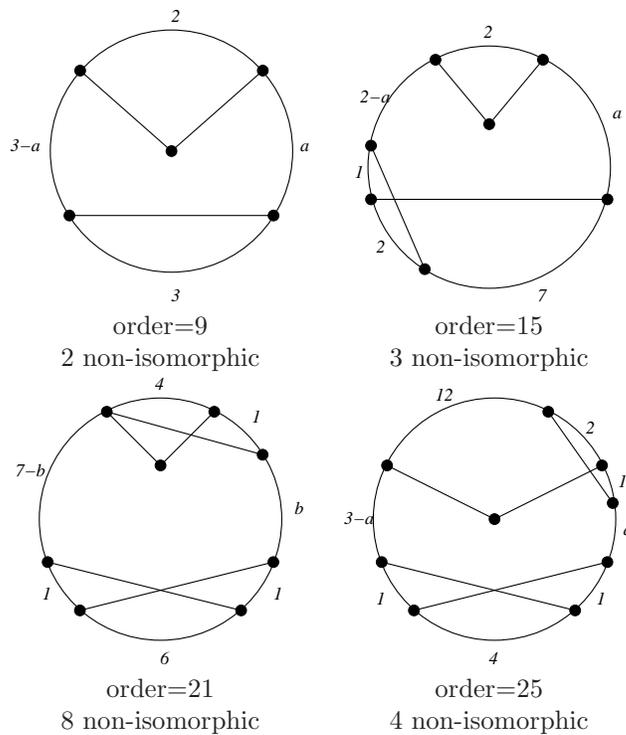


Figure 8: The oddly (2)-bipancyclic graphs with  $v$  vertices and  $(v - 1) + m$  edges, where  $m \leq 5$ .

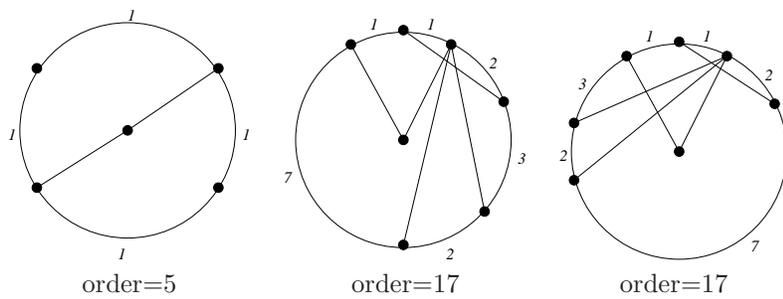


Figure 9: The oddly (3)-bipancyclic graphs with  $v$  vertices and  $(v - 1) + m$  edges, where  $m \leq 5$ .

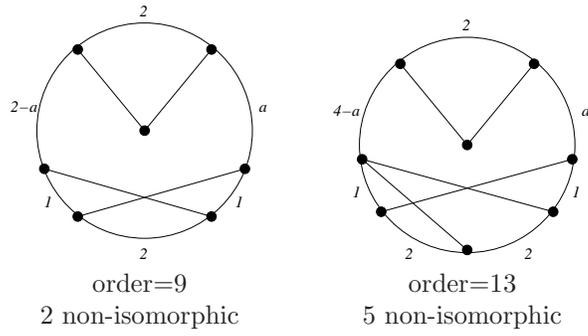


Figure 10: The oddly (4)-bipancyclic graphs with  $v$  vertices and  $(v-1)+m$  edges, where  $m \leq 5$ .