I. (31 marks in total; continued on next two pages) General questions about database systems, the relational model and about the SQL standard. Answer each of the following using no more than a few sentences in each case.

(5 marks) Explain how physical data independence can decrease the cost of maintaining an information system.

Physical data independence enables a separation of concerns between physical database design and applications development. An important consequence is that physical design can then be modified to accommodate changes in workload without any need to recode applications.

(5 marks) What are the two general problems that are addressed by adopting the use of database technology when implementing an information systems?

1. Problems relating to concurrent execution of threads or processes, and
2. Problems relating to durability requirements of underlying data.
(6 marks) Explain each of the following terms.

1. durability

Durability is a reliability issue, in particular the reliability that a database and any committed transactions are never lost.

2. transaction

A sequence of primitive operations that comprise a meaningful revision or consistency preserving transformation on a database.

3. domain independence

A property of a relational calculus query that ensures changes to only an underlying domain of a database will not change the result of the query.

(4 marks) Describe the primary means of defining external views in the SQL language.

The GRANT and REVOKE commands.
(8 marks) Assume relation $R$ has numeric attributes \{A, B, C\}, with C as the primary key. Express the following query in the range restricted fragment of the relational calculus.

```sql
select distinct r1.A from R r1, R r2
where r1.C = r2.A
and not exists ( select * from R r3
```


(3 marks) What are three features of the SQL query language that make it more expressive than the relational calculus?

1. Multiset or bag semantics that enable queries to compute tables with more than one copy of tuples,

2. An ability to aggregate values, such as the number of rows in a table or the sum of numeric values occurring in a column of a table.

3. An ability to sort.