Question 1. *(10 points) Describe the difference between internal and external fragmentation. What effect does paging have on each type of fragmentation?*

Question 2. *(15 points) Explain why systems using paging usually choose a page size that is a power of 2 (e.g., $2^8 = 256$ bytes, $2^9 = 512$ bytes, etc). What is the disadvantage of choosing a page size that is not a power of 2?*

Question 3. *(25 points) Consider a byte-addressable system with 32 byte pages and a total memory size of 512 bytes.*

1. *(5 points) How many bits are needed for an address? Of these, how many bits are needed for the page number (p) and how many for the offset (d)?*

2. *(10 points) Assuming the (partial) page table shown below, translate virtual address "124" to a physical address (i.e., the kth byte of physical memory). Show your calculations.*

Page	Frame
0	5
1	12
2	9
3	7
4	15
...	...

3. *(10 points) Suppose you extend your paging system to support segmented paging, where each process will have 7 segments. All other aspects of the memory system will remain the same as described above, and each segment is allowed to use up to the full 512 bytes of memory. How many bits will be needed to encode a virtual address? How many bits for a physical address?*

Question 4. *(10 points) Explain why a valid bit is necessary in the translation look-aside buffer (TLB) of a paged memory system.*

Question 5. *(10 points) Determine how the FIFO and MIN page replacement algorithms would handle the following page access pattern:* $A, B, C, D, E, A, B, E, D, B, B, A$. *As in the figures below, assume that the system has three frames of memory (each which can hold a single virtual page). Using tables like the ones below, fill in the frame contents for each step of the access pattern and report the total number of page faults for each algorithm.*

FIFO	A	B	C	D	E	A	B	E	D	B	B	A
F1												
F2												
F3												
Fault?												

MIN	A	B	C	D	E	A	B	E	D	B	B	A
F1												
F2												
F3												
Fault?												

Question 6. *(15 points) Explain how the second-chance (clock) algorithm approximates LRU page replacement. Don't simply state what the algorithm does; instead, clearly explain how it is related to an actual LRU replacement scheme.*

Question 7. *(15 points) Explain why a high degree of multiprogramming (i.e., many processes running at once) can lead to a situation in which the CPU utilization of the machine drops to near zero.*