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

Question 2. *(10 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 system with 32 byte pages and a total memory size of 2048 bytes. Assume that the system can access individual 4-byte words as the smallest unit of memory addressing (i.e., as in a typical 32-bit system). Recall that this means that an offset of 2 into a page means the third 4-byte word of the page (i.e., bytes 8-11).*

1. *(5 points) What is the total number of addressable words supported by this memory? How many different pages per process can be supported?*

2. *(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)?*

3. *(8 points) Assuming the (partial) page table shown below, translate virtual address "28" to a physical address (i.e., the kth word of physical memory). Be sure to complete the calculation and give the actual set of physical memory bytes that this address corresponds to.*

Page	Frame
0	5
1	14
2	9
3	7
4	18
...	...

4. *(7 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. How many bits will be needed to encode a virtual address? How many bits for a physical address?*

Question 4. *(15 points) Explain why the addition of a translation look-aside buffer (TLB) is important in a paged memory system.*

Question 5. *(15 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. *(10 points) What is the benefit of adding a modify bit to the second-chance page replacement algorithm (aka clock algorithm)?*

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.*