1. **Answer:**

a)

- Relative address is 5499 = 5 × 1024 + 379, i.e., virtual address is 5, 379
- Map to frame number 0
- The physical address is 0 × 1024 + 379 = 379.

b)

- Relative address is 2221 = 2 × 1024 + 173, i.e., virtual address is 2, 173
- The page has not been loaded into memory yet, resulting in a page fault

2. **Answer:**

a) A frame has the same size as a page, 1 Kbytes = 2^{10} bytes

b) 2^{32} bytes = 4-Gbyte

c) The maximum number of pages in the virtual address space is $2^{32} / 2^{10} = 2^{22}$. There is one entry for each page. Therefore, there are 2^{22} entries.

d)

- The 1st level page table size will be $2^{22} \times 2^2$ bytes.
- The 1st level page table can be divided into (2^{24} bytes of page table) / (2^{10} bytes/page) = **2^{14} pages**.
- The 2nd level page table size will be $2^{14} \times 2^2 = 2^{16}$ bytes.
- The 2nd level page table can be further divided into (2^{16} bytes of page table) / (2^{10} bytes/page) = **2^6 pages**.
- The 3rd level page table size will be $2^6 \times 2^2 = 2^8$ bytes, which can be fit into **one single page**.

Therefore, 3 levels of page tables are needed, with the size of 1 page, 64 (2^6) pages, and 16,384 (2^{14}) pages respectively.

3. **Answer:**

a) 2K × 8 = 16KB

b) 16K × 4 = 64KB

4. **Answer**:

a) **OPT:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	2	2	2	2	2	2
	0	0	0	0	0	0	4	4	4	0	0	0
		1	1	1	3	3	3	3	3	3	3	3
F	F	F	F		F		F			F		

number of page faults = 7

b) **FIFO:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	4	4	4	0	0	0
	0	0	0	0	3	3	3	2	2	2	2	2
		1	1	1	1	0	0	0	3	3	3	3
F	F	F	F		F	F	F	F	F	F		

number of page faults = 10

c) **LRU:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	4	4	4	0	0	0
	0	0	0	0	0	0	0	0	3	3	3	3
		1	1	1	3	3	3	2	2	2	2	2
F	F	F	F		F		F	F	F	F		

number of page faults = 9

d) **Clock:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7*	7*	→7*	2*	2*	→2*	→2*	4*	4*	4*	→4	3*	3*
→	0*	0*	→0	→0*	0	0*	→0	2*	2*	2	→2	→2*
	→	1*	1	1	3*	3*	3	→3	→3*	0*	0*	0*
F	F	F	F		F		F	F		F	F	

number of page faults = 9

Self-test

1. C
2. C
3. B
4. A
5. D
6. C