Problem 1. Let $U$ be a finite set, and let $H$ be the collection of all hash functions $f : U \rightarrow \{0, \ldots, m - 1\}$.

(a) Prove that $H$ is universal.

(b) Suppose that you design an algorithm that samples uniformly at random a hash function $h \in H$, stores $h$ in memory, and then uses $h$ to hash $n$ keys into a hash table of size $m$. Assume that $|U| \gg n \gg m$. How much space does your algorithm use? Hint: Your findings should convince you that $H$ is not a good choice of a universal collection of hash functions.

Problem 2. Let $r, m > 0$ be integers. Let $U = \{0, \ldots, m \cdot r - 1\}$ be the set of all possible keys. For any $i \in U$, let $f_i : U \rightarrow \{0, \ldots, m - 1\}$ be the function such that for any $k \in U$, we have $f_i(k) = (k + i) \mod m$.

Let $H$ be the collection of all such hash functions, i.e. $H = \{f_0, f_1, \ldots, f_{m \cdot r - 1}\}$. Is $H$ universal?

Problem 3. Suppose we use a hash function $h$ to hash $n$ distinct keys into an array of length $m$. Assuming simple uniform hashing, what is the expected number of collisions? That is, you have to compute the expected cardinality of the set $S = \{\{k, l\} : k \neq l \text{ and } h(k) = h(l)\}$.

Hint: For any pair of distinct keys $k, l$, define the indicator random variable $X_{kl} = I\{h(k) = h(l)\}$. That is, the random variable $X_{kl}$ takes the value 1 when $h(k) = h(l)$, and the value 0 when $h(k) \neq h(l)$. Argue that $|S| = \sum_{k \neq l} X_{kl}$. Apply linearity of expectation to derive an estimate on the expected size of $S$, i.e. $E[|S|]$. 