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Assignment 8

Aim: To encrypt given plain text using AES algorithm.

Theory:

Advanced Encryption Standard (AES) is a specification for the encryption of electronic data established by the U.S National Institute of Standards and Technology (NIST) in 2001. AES is widely used today as it is a much stronger than DES and triple DES despite being harder to implement.

Code:

```
#include <bits/stdc++.h>
using namespace std;

unsigned char s[256] =
    {
        0x63, 0x7C, 0x77, 0x7B, 0xF2, 0x6B, 0x6F,
0xC5, 0x30, 0x01, 0x67, 0x2B, 0xFE, 0xD7, 0xAB,
0x76,
        0xCA, 0x82, 0xC9, 0x7D, 0xFA, 0x59, 0x47,
0xF0, 0xAD, 0xD4, 0xA2, 0xAF, 0x9C, 0xA4, 0x72,
0xC0,
        0xB7, 0xFD, 0x93, 0x26, 0x36, 0x3F, 0xF7,
0xCC, 0x34, 0xA5, 0xE5, 0xF1, 0x71, 0xD8, 0x31,
0x15,
```

```
        0x04, 0xC7, 0x23, 0xC3, 0x18, 0x96, 0x05,
0x9A, 0x07, 0x12, 0x80, 0xE2, 0xEB, 0x27, 0xB2,
0x75,
        0x09, 0x83, 0x2C, 0x1A, 0x1B, 0x6E, 0x5A,
0xA0, 0x52, 0x3B, 0xD6, 0xB3, 0x29, 0xE3, 0x2F,
0x84,
        0x53, 0xD1, 0x00, 0xED, 0x20, 0xFC, 0xB1,
0x5B, 0x6A, 0xCB, 0xBE, 0x39, 0x4A, 0x4C, 0x58,
0xCF,
        0xD0, 0xEF, 0xAA, 0xFB, 0x43, 0x4D, 0x33,
0x85, 0x45, 0xF9, 0x02, 0x7F, 0x50, 0x3C, 0x9F,
0xA8,
        0x51, 0xA3, 0x40, 0x8F, 0x92, 0x9D, 0x38,
0xF5, 0xBC, 0xB6, 0xDA, 0x21, 0x10, 0xFF, 0xF3,
0xD2,
        0xCD, 0x0C, 0x13, 0xEC, 0x5F, 0x97, 0x44,
0x17, 0xC4, 0xA7, 0x7E, 0x3D, 0x64, 0x5D, 0x19,
0x73,
        0x60, 0x81, 0x4F, 0xDC, 0x22, 0x2A, 0x90,
0x88, 0x46, 0xEE, 0xB8, 0x14, 0xDE, 0x5E, 0x0B,
0xDB,
        0xE0, 0x32, 0x3A, 0x0A, 0x49, 0x06, 0x24,
0x5C, 0xC2, 0xD3, 0xAC, 0x62, 0x91, 0x95, 0xE4,
0x79,
        0xE7, 0xC8, 0x37, 0x6D, 0x8D, 0xD5, 0x4E,
0xA9, 0x6C, 0x56, 0xF4, 0xEA, 0x65, 0x7A, 0xAE,
0x08,
```

```
        0xBA, 0x78, 0x25, 0x2E, 0x1C, 0xA6, 0xB4,
0xC6, 0xE8, 0xDD, 0x74, 0x1F, 0x4B, 0xBD, 0x8B,
0x8A,
        0x70, 0x3E, 0xB5, 0x66, 0x48, 0x03, 0xF6,
0x0E, 0x61, 0x35, 0x57, 0xB9, 0x86, 0xC1, 0x1D,
0x9E,
        0xE1, 0xF8, 0x98, 0x11, 0x69, 0xD9, 0x8E,
0x94, 0x9B, 0x1E, 0x87, 0xE9, 0xCE, 0x55, 0x28,
0xDF,
        0x8C, 0xA1, 0x89, 0x0D, 0xBF, 0xE6, 0x42,
0x68, 0x41, 0x99, 0x2D, 0x0F, 0xB0, 0x54, 0xBB,
0x16};

// Encryption: Multiply by 2 for MixColumns
unsigned char mul2[] =
    {
        0x00, 0x02, 0x04, 0x06, 0x08, 0x0a, 0x0c,
0x0e, 0x10, 0x12, 0x14, 0x16, 0x18, 0x1a, 0x1c,
0x1e,
        0x20, 0x22, 0x24, 0x26, 0x28, 0x2a, 0x2c,
0x2e, 0x30, 0x32, 0x34, 0x36, 0x38, 0x3a, 0x3c,
0x3e,
        0x40, 0x42, 0x44, 0x46, 0x48, 0x4a, 0x4c,
0x4e, 0x50, 0x52, 0x54, 0x56, 0x58, 0x5a, 0x5c,
0x5e,
        0x60, 0x62, 0x64, 0x66, 0x68, 0x6a, 0x6c,
0x6e, 0x70, 0x72, 0x74, 0x76, 0x78, 0x7a, 0x7c,
0x7e,
```

```
        0x80, 0x82, 0x84, 0x86, 0x88, 0x8a, 0x8c,
0x8e, 0x90, 0x92, 0x94, 0x96, 0x98, 0x9a, 0x9c,
0x9e,
        0xa0, 0xa2, 0xa4, 0xa6, 0xa8, 0xaa, 0xac,
0xae, 0xb0, 0xb2, 0xb4, 0xb6, 0xb8, 0xba, 0xbc,
0xbe,
        0xc0, 0xc2, 0xc4, 0xc6, 0xc8, 0xca, 0xcc,
0xce, 0xd0, 0xd2, 0xd4, 0xd6, 0xd8, 0xda, 0xdc,
0xde,
        0xe0, 0xe2, 0xe4, 0xe6, 0xe8, 0xea, 0xec,
0xee, 0xf0, 0xf2, 0xf4, 0xf6, 0xf8, 0xfa, 0xfc,
0xfe,
        0x1b, 0x19, 0x1f, 0x1d, 0x13, 0x11, 0x17,
0x15, 0x0b, 0x09, 0x0f, 0x0d, 0x03, 0x01, 0x07,
0x05,
        0x3b, 0x39, 0x3f, 0x3d, 0x33, 0x31, 0x37,
0x35, 0x2b, 0x29, 0x2f, 0x2d, 0x23, 0x21, 0x27,
0x25,
        0x5b, 0x59, 0x5f, 0x5d, 0x53, 0x51, 0x57,
0x55, 0x4b, 0x49, 0x4f, 0x4d, 0x43, 0x41, 0x47,
0x45,
        0x7b, 0x79, 0x7f, 0x7d, 0x73, 0x71, 0x77,
0x75, 0x6b, 0x69, 0x6f, 0x6d, 0x63, 0x61, 0x67,
0x65,
        0x9b, 0x99, 0x9f, 0x9d, 0x93, 0x91, 0x97,
0x95, 0x8b, 0x89, 0x8f, 0x8d, 0x83, 0x81, 0x87,
0x85,
```

```
        0xbb, 0xb9, 0xbf, 0xbd, 0xb3, 0xb1, 0xb7,
0xb5, 0xab, 0xa9, 0xaf, 0xad, 0xa3, 0xa1, 0xa7,
0xa5,
        0xdb, 0xd9, 0xdf, 0xdd, 0xd3, 0xd1, 0xd7,
0xd5, 0xcb, 0xc9, 0xcf, 0xcd, 0xc3, 0xc1, 0xc7,
0xc5,
        0xfb, 0xf9, 0xff, 0xfd, 0xf3, 0xf1, 0xf7,
0xf5, 0xeb, 0xe9, 0xef, 0xed, 0xe3, 0xe1, 0xe7,
0xe5};

// Encryption: Multiply by 3 for MixColumns
unsigned char mul3[] =
    {
        0x00, 0x03, 0x06, 0x05, 0x0c, 0x0f, 0x0a,
0x09, 0x18, 0x1b, 0x1e, 0x1d, 0x14, 0x17, 0x12,
0x11,
        0x30, 0x33, 0x36, 0x35, 0x3c, 0x3f, 0x3a,
0x39, 0x28, 0x2b, 0x2e, 0x2d, 0x24, 0x27, 0x22,
0x21,
        0x60, 0x63, 0x66, 0x65, 0x6c, 0x6f, 0x6a,
0x69, 0x78, 0x7b, 0x7e, 0x7d, 0x74, 0x77, 0x72,
0x71,
        0x50, 0x53, 0x56, 0x55, 0x5c, 0x5f, 0x5a,
0x59, 0x48, 0x4b, 0x4e, 0x4d, 0x44, 0x47, 0x42,
0x41,
        0xc0, 0xc3, 0xc6, 0xc5, 0xcc, 0xcf, 0xca,
0xc9, 0xd8, 0xdb, 0xde, 0xdd, 0xd4, 0xd7, 0xd2,
0xd1,
```

```
        0xf0, 0xf3, 0xf6, 0xf5, 0xfc, 0xff, 0xfa,
0xf9, 0xe8, 0xeb, 0xee, 0xed, 0xe4, 0xe7, 0xe2,
0xe1,
        0xa0, 0xa3, 0xa6, 0xa5, 0xac, 0xaf, 0xaa,
0xa9, 0xb8, 0xbb, 0xbe, 0xbd, 0xb4, 0xb7, 0xb2,
0xb1,
        0x90, 0x93, 0x96, 0x95, 0x9c, 0x9f, 0x9a,
0x99, 0x88, 0x8b, 0x8e, 0x8d, 0x84, 0x87, 0x82,
0x81,
        0x9b, 0x98, 0x9d, 0x9e, 0x97, 0x94, 0x91,
0x92, 0x83, 0x80, 0x85, 0x86, 0x8f, 0x8c, 0x89,
0x8a,
        0xab, 0xa8, 0xad, 0xae, 0xa7, 0xa4, 0xa1,
0xa2, 0xb3, 0xb0, 0xb5, 0xb6, 0xbf, 0xbc, 0xb9,
0xba,
        0xfb, 0xf8, 0xfd, 0xfe, 0xf7, 0xf4, 0xf1,
0xf2, 0xe3, 0xe0, 0xe5, 0xe6, 0xef, 0xec, 0xe9,
0xea,
        0xcb, 0xc8, 0xcd, 0xce, 0xc7, 0xc4, 0xc1,
0xc2, 0xd3, 0xd0, 0xd5, 0xd6, 0xdf, 0xdc, 0xd9,
0xda,
        0x5b, 0x58, 0x5d, 0x5e, 0x57, 0x54, 0x51,
0x52, 0x43, 0x40, 0x45, 0x46, 0x4f, 0x4c, 0x49,
0x4a,
        0x6b, 0x68, 0x6d, 0x6e, 0x67, 0x64, 0x61,
0x62, 0x73, 0x70, 0x75, 0x76, 0x7f, 0x7c, 0x79,
0x7a,
```

```
        0x3b, 0x38, 0x3d, 0x3e, 0x37, 0x34, 0x31,
0x32, 0x23, 0x20, 0x25, 0x26, 0x2f, 0x2c, 0x29,
0x2a,
        0x0b, 0x08, 0x0d, 0x0e, 0x07, 0x04, 0x01,
0x02, 0x13, 0x10, 0x15, 0x16, 0x1f, 0x1c, 0x19,
0x1a};

// Used in KeyExpansion
unsigned char rcon[256] = {
    0x8d, 0x01, 0x02, 0x04, 0x08, 0x10, 0x20, 0x40,
0x80, 0x1b, 0x36, 0x6c, 0xd8, 0xab, 0x4d, 0x9a,
    0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a,
0xd4, 0xb3, 0x7d, 0xfa, 0xef, 0xc5, 0x91, 0x39,
    0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f, 0x25,
0x4a, 0x94, 0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a,
    0x74, 0xe8, 0xcb, 0x8d, 0x01, 0x02, 0x04, 0x08,
0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8,
    0xab, 0x4d, 0x9a, 0x2f, 0x5e, 0xbc, 0x63, 0xc6,
0x97, 0x35, 0x6a, 0xd4, 0xb3, 0x7d, 0xfa, 0xef,
    0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61,
0xc2, 0x9f, 0x25, 0x4a, 0x94, 0x33, 0x66, 0xcc,
    0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb, 0x8d, 0x01,
0x02, 0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x1b,
    0x36, 0x6c, 0xd8, 0xab, 0x4d, 0x9a, 0x2f, 0x5e,
0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3,
    0x7d, 0xfa, 0xef, 0xc5, 0x91, 0x39, 0x72, 0xe4,
0xd3, 0xbd, 0x61, 0xc2, 0x9f, 0x25, 0x4a, 0x94,
    0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8,
0xcb, 0x8d, 0x01, 0x02, 0x04, 0x08, 0x10, 0x20,
```

```
    0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8, 0xab, 0x4d,
0x9a, 0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35,
    0x6a, 0xd4, 0xb3, 0x7d, 0xfa, 0xef, 0xc5, 0x91,
0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f,
    0x25, 0x4a, 0x94, 0x33, 0x66, 0xcc, 0x83, 0x1d,
0x3a, 0x74, 0xe8, 0xcb, 0x8d, 0x01, 0x02, 0x04,
    0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c,
0xd8, 0xab, 0x4d, 0x9a, 0x2f, 0x5e, 0xbc, 0x63,
    0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3, 0x7d, 0xfa,
0xef, 0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd,
    0x61, 0xc2, 0x9f, 0x25, 0x4a, 0x94, 0x33, 0x66,
0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb, 0x8d};

// Decryption: Inverse Rijndael S-box
unsigned char inv_s[256] =
    {
        0x52, 0x09, 0x6A, 0xD5, 0x30, 0x36, 0xA5,
0x38, 0xBF, 0x40, 0xA3, 0x9E, 0x81, 0xF3, 0xD7,
0xFB,
        0x7C, 0xE3, 0x39, 0x82, 0x9B, 0x2F, 0xFF,
0x87, 0x34, 0x8E, 0x43, 0x44, 0xC4, 0xDE, 0xE9,
0xCB,
        0x54, 0x7B, 0x94, 0x32, 0xA6, 0xC2, 0x23,
0x3D, 0xEE, 0x4C, 0x95, 0x0B, 0x42, 0xFA, 0xC3,
0x4E,
        0x08, 0x2E, 0xA1, 0x66, 0x28, 0xD9, 0x24,
0xB2, 0x76, 0x5B, 0xA2, 0x49, 0x6D, 0x8B, 0xD1,
0x25,
```

```
        0x72, 0xF8, 0xF6, 0x64, 0x86, 0x68, 0x98,
0x16, 0xD4, 0xA4, 0x5C, 0xCC, 0x5D, 0x65, 0xB6,
0x92,
        0x6C, 0x70, 0x48, 0x50, 0xFD, 0xED, 0xB9,
0xDA, 0x5E, 0x15, 0x46, 0x57, 0xA7, 0x8D, 0x9D,
0x84,
        0x90, 0xD8, 0xAB, 0x00, 0x8C, 0xBC, 0xD3,
0x0A, 0xF7, 0xE4, 0x58, 0x05, 0xB8, 0xB3, 0x45,
0x06,
        0xD0, 0x2C, 0x1E, 0x8F, 0xCA, 0x3F, 0x0F,
0x02, 0xC1, 0xAF, 0xBD, 0x03, 0x01, 0x13, 0x8A,
0x6B,
        0x3A, 0x91, 0x11, 0x41, 0x4F, 0x67, 0xDC,
0xEA, 0x97, 0xF2, 0xCF, 0xCE, 0xF0, 0xB4, 0xE6,
0x73,
        0x96, 0xAC, 0x74, 0x22, 0xE7, 0xAD, 0x35,
0x85, 0xE2, 0xF9, 0x37, 0xE8, 0x1C, 0x75, 0xDF,
0x6E,
        0x47, 0xF1, 0x1A, 0x71, 0x1D, 0x29, 0xC5,
0x89, 0x6F, 0xB7, 0x62, 0x0E, 0xAA, 0x18, 0xBE,
0x1B,
        0xFC, 0x56, 0x3E, 0x4B, 0xC6, 0xD2, 0x79,
0x20, 0x9A, 0xDB, 0xC0, 0xFE, 0x78, 0xCD, 0x5A,
0xF4,
        0x1F, 0xDD, 0xA8, 0x33, 0x88, 0x07, 0xC7,
0x31, 0xB1, 0x12, 0x10, 0x59, 0x27, 0x80, 0xEC,
0x5F,
```

```
        0x60, 0x51, 0x7F, 0xA9, 0x19, 0xB5, 0x4A,
0x0D, 0x2D, 0xE5, 0x7A, 0x9F, 0x93, 0xC9, 0x9C,
0xEF,
        0xA0, 0xE0, 0x3B, 0x4D, 0xAE, 0x2A, 0xF5,
0xB0, 0xC8, 0xEB, 0xBB, 0x3C, 0x83, 0x53, 0x99,
0x61,
        0x17, 0x2B, 0x04, 0x7E, 0xBA, 0x77, 0xD6,
0x26, 0xE1, 0x69, 0x14, 0x63, 0x55, 0x21, 0x0C,
0x7D};

// Decryption: Multiply by 9 for InverseMixColumns
unsigned char mul9[256] =
    {
        0x00, 0x09, 0x12, 0x1b, 0x24, 0x2d, 0x36,
0x3f, 0x48, 0x41, 0x5a, 0x53, 0x6c, 0x65, 0x7e,
0x77,
        0x90, 0x99, 0x82, 0x8b, 0xb4, 0xbd, 0xa6,
0xaf, 0xd8, 0xd1, 0xca, 0xc3, 0xfc, 0xf5, 0xee,
0xe7,
        0x3b, 0x32, 0x29, 0x20, 0x1f, 0x16, 0x0d,
0x04, 0x73, 0x7a, 0x61, 0x68, 0x57, 0x5e, 0x45,
0x4c,
        0xab, 0xa2, 0xb9, 0xb0, 0x8f, 0x86, 0x9d,
0x94, 0xe3, 0xea, 0xf1, 0xf8, 0xc7, 0xce, 0xd5,
0xdc,
        0x76, 0x7f, 0x64, 0x6d, 0x52, 0x5b, 0x40,
0x49, 0x3e, 0x37, 0x2c, 0x25, 0x1a, 0x13, 0x08,
0x01,
```

```
        0xe6, 0xef, 0xf4, 0xfd, 0xc2, 0xcb, 0xd0,
0xd9, 0xae, 0xa7, 0xbc, 0xb5, 0x8a, 0x83, 0x98,
0x91,
        0x4d, 0x44, 0x5f, 0x56, 0x69, 0x60, 0x7b,
0x72, 0x05, 0x0c, 0x17, 0x1e, 0x21, 0x28, 0x33,
0x3a,
        0xdd, 0xd4, 0xcf, 0xc6, 0xf9, 0xf0, 0xeb,
0xe2, 0x95, 0x9c, 0x87, 0x8e, 0xb1, 0xb8, 0xa3,
0xaa,
        0xec, 0xe5, 0xfe, 0xf7, 0xc8, 0xc1, 0xda,
0xd3, 0xa4, 0xad, 0xb6, 0xbf, 0x80, 0x89, 0x92,
0x9b,
        0x7c, 0x75, 0x6e, 0x67, 0x58, 0x51, 0x4a,
0x43, 0x34, 0x3d, 0x26, 0x2f, 0x10, 0x19, 0x02,
0x0b,
        0xd7, 0xde, 0xc5, 0xcc, 0xf3, 0xfa, 0xe1,
0xe8, 0x9f, 0x96, 0x8d, 0x84, 0xbb, 0xb2, 0xa9,
0xa0,
        0x47, 0x4e, 0x55, 0x5c, 0x63, 0x6a, 0x71,
0x78, 0x0f, 0x06, 0x1d, 0x14, 0x2b, 0x22, 0x39,
0x30,
        0x9a, 0x93, 0x88, 0x81, 0xbe, 0xb7, 0xac,
0xa5, 0xd2, 0xdb, 0xc0, 0xc9, 0xf6, 0xff, 0xe4,
0xed,
        0x0a, 0x03, 0x18, 0x11, 0x2e, 0x27, 0x3c,
0x35, 0x42, 0x4b, 0x50, 0x59, 0x66, 0x6f, 0x74,
0x7d,
```

```
        0xa1, 0xa8, 0xb3, 0xba, 0x85, 0x8c, 0x97,
0x9e, 0xe9, 0xe0, 0xfb, 0xf2, 0xcd, 0xc4, 0xdf,
0xd6,
        0x31, 0x38, 0x23, 0x2a, 0x15, 0x1c, 0x07,
0x0e, 0x79, 0x70, 0x6b, 0x62, 0x5d, 0x54, 0x4f,
0x46};

// Decryption: Multiply by 11 for InverseMixColumns
unsigned char mul11[256] =
    {
        0x00, 0x0b, 0x16, 0x1d, 0x2c, 0x27, 0x3a,
0x31, 0x58, 0x53, 0x4e, 0x45, 0x74, 0x7f, 0x62,
0x69,
        0xb0, 0xbb, 0xa6, 0xad, 0x9c, 0x97, 0x8a,
0x81, 0xe8, 0xe3, 0xfe, 0xf5, 0xc4, 0xcf, 0xd2,
0xd9,
        0x7b, 0x70, 0x6d, 0x66, 0x57, 0x5c, 0x41,
0x4a, 0x23, 0x28, 0x35, 0x3e, 0x0f, 0x04, 0x19,
0x12,
        0xcb, 0xc0, 0xdd, 0xd6, 0xe7, 0xec, 0xf1,
0xfa, 0x93, 0x98, 0x85, 0x8e, 0xbf, 0xb4, 0xa9,
0xa2,
        0xf6, 0xfd, 0xe0, 0xeb, 0xda, 0xd1, 0xcc,
0xc7, 0xae, 0xa5, 0xb8, 0xb3, 0x82, 0x89, 0x94,
0x9f,
        0x46, 0x4d, 0x50, 0x5b, 0x6a, 0x61, 0x7c,
0x77, 0x1e, 0x15, 0x08, 0x03, 0x32, 0x39, 0x24,
0x2f,
```

```
        0x8d, 0x86, 0x9b, 0x90, 0xa1, 0xaa, 0xb7,
0xbc, 0xd5, 0xde, 0xc3, 0xc8, 0xf9, 0xf2, 0xef,
0xe4,
        0x3d, 0x36, 0x2b, 0x20, 0x11, 0x1a, 0x07,
0x0c, 0x65, 0x6e, 0x73, 0x78, 0x49, 0x42, 0x5f,
0x54,
        0xf7, 0xfc, 0xe1, 0xea, 0xdb, 0xd0, 0xcd,
0xc6, 0xaf, 0xa4, 0xb9, 0xb2, 0x83, 0x88, 0x95,
0x9e,
        0x47, 0x4c, 0x51, 0x5a, 0x6b, 0x60, 0x7d,
0x76, 0x1f, 0x14, 0x09, 0x02, 0x33, 0x38, 0x25,
0x2e,
        0x8c, 0x87, 0x9a, 0x91, 0xa0, 0xab, 0xb6,
0xbd, 0xd4, 0xdf, 0xc2, 0xc9, 0xf8, 0xf3, 0xee,
0xe5,
        0x3c, 0x37, 0x2a, 0x21, 0x10, 0x1b, 0x06,
0x0d, 0x64, 0x6f, 0x72, 0x79, 0x48, 0x43, 0x5e,
0x55,
        0x01, 0x0a, 0x17, 0x1c, 0x2d, 0x26, 0x3b,
0x30, 0x59, 0x52, 0x4f, 0x44, 0x75, 0x7e, 0x63,
0x68,
        0xb1, 0xba, 0xa7, 0xac, 0x9d, 0x96, 0x8b,
0x80, 0xe9, 0xe2, 0xff, 0xf4, 0xc5, 0xce, 0xd3,
0xd8,
        0x7a, 0x71, 0x6c, 0x67, 0x56, 0x5d, 0x40,
0x4b, 0x22, 0x29, 0x34, 0x3f, 0x0e, 0x05, 0x18,
0x13,
```

```
        0xca, 0xc1, 0xdc, 0xd7, 0xe6, 0xed, 0xf0,
0xfb, 0x92, 0x99, 0x84, 0x8f, 0xbe, 0xb5, 0xa8,
0xa3};

// Decryption: Multiply by 13 for InverseMixColumns
unsigned char mul13[256] =
    {
        0x00, 0x0d, 0x1a, 0x17, 0x34, 0x39, 0x2e,
0x23, 0x68, 0x65, 0x72, 0x7f, 0x5c, 0x51, 0x46,
0x4b,
        0xd0, 0xdd, 0xca, 0xc7, 0xe4, 0xe9, 0xfe,
0xf3, 0xb8, 0xb5, 0xa2, 0xaf, 0x8c, 0x81, 0x96,
0x9b,
        0xbb, 0xb6, 0xa1, 0xac, 0x8f, 0x82, 0x95,
0x98, 0xd3, 0xde, 0xc9, 0xc4, 0xe7, 0xea, 0xfd,
0xf0,
        0x6b, 0x66, 0x71, 0x7c, 0x5f, 0x52, 0x45,
0x48, 0x03, 0x0e, 0x19, 0x14, 0x37, 0x3a, 0x2d,
0x20,
        0x6d, 0x60, 0x77, 0x7a, 0x59, 0x54, 0x43,
0x4e, 0x05, 0x08, 0x1f, 0x12, 0x31, 0x3c, 0x2b,
0x26,
        0xbd, 0xb0, 0xa7, 0xaa, 0x89, 0x84, 0x93,
0x9e, 0xd5, 0xd8, 0xcf, 0xc2, 0xe1, 0xec, 0xfb,
0xf6,
        0xd6, 0xdb, 0xcc, 0xc1, 0xe2, 0xef, 0xf8,
0xf5, 0xbe, 0xb3, 0xa4, 0xa9, 0x8a, 0x87, 0x90,
0x9d,
```

```
        0x06, 0x0b, 0x1c, 0x11, 0x32, 0x3f, 0x28,
0x25, 0x6e, 0x63, 0x74, 0x79, 0x5a, 0x57, 0x40,
0x4d,
        0xda, 0xd7, 0xc0, 0xcd, 0xee, 0xe3, 0xf4,
0xf9, 0xb2, 0xbf, 0xa8, 0xa5, 0x86, 0x8b, 0x9c,
0x91,
        0x0a, 0x07, 0x10, 0x1d, 0x3e, 0x33, 0x24,
0x29, 0x62, 0x6f, 0x78, 0x75, 0x56, 0x5b, 0x4c,
0x41,
        0x61, 0x6c, 0x7b, 0x76, 0x55, 0x58, 0x4f,
0x42, 0x09, 0x04, 0x13, 0x1e, 0x3d, 0x30, 0x27,
0x2a,
        0xb1, 0xbc, 0xab, 0xa6, 0x85, 0x88, 0x9f,
0x92, 0xd9, 0xd4, 0xc3, 0xce, 0xed, 0xe0, 0xf7,
0xfa,
        0xb7, 0xba, 0xad, 0xa0, 0x83, 0x8e, 0x99,
0x94, 0xdf, 0xd2, 0xc5, 0xc8, 0xeb, 0xe6, 0xf1,
0xfc,
        0x67, 0x6a, 0x7d, 0x70, 0x53, 0x5e, 0x49,
0x44, 0x0f, 0x02, 0x15, 0x18, 0x3b, 0x36, 0x21,
0x2c,
        0x0c, 0x01, 0x16, 0x1b, 0x38, 0x35, 0x22,
0x2f, 0x64, 0x69, 0x7e, 0x73, 0x50, 0x5d, 0x4a,
0x47,
        0xdc, 0xd1, 0xc6, 0xcb, 0xe8, 0xe5, 0xf2,
0xff, 0xb4, 0xb9, 0xae, 0xa3, 0x80, 0x8d, 0x9a,
0x97};

// Decryption: Multiply by 14 for InverseMixColumns
```

```
unsigned char mul14[256] =
    {
        0x00, 0x0e, 0x1c, 0x12, 0x38, 0x36, 0x24,
0x2a, 0x70, 0x7e, 0x6c, 0x62, 0x48, 0x46, 0x54,
0x5a,
        0xe0, 0xee, 0xfc, 0xf2, 0xd8, 0xd6, 0xc4,
0xca, 0x90, 0x9e, 0x8c, 0x82, 0xa8, 0xa6, 0xb4,
0xba,
        0xdb, 0xd5, 0xc7, 0xc9, 0xe3, 0xed, 0xff,
0xf1, 0xab, 0xa5, 0xb7, 0xb9, 0x93, 0x9d, 0x8f,
0x81,
        0x3b, 0x35, 0x27, 0x29, 0x03, 0x0d, 0x1f,
0x11, 0x4b, 0x45, 0x57, 0x59, 0x73, 0x7d, 0x6f,
0x61,
        0xad, 0xa3, 0xb1, 0xbf, 0x95, 0x9b, 0x89,
0x87, 0xdd, 0xd3, 0xc1, 0xcf, 0xe5, 0xeb, 0xf9,
0xf7,
        0x4d, 0x43, 0x51, 0x5f, 0x75, 0x7b, 0x69,
0x67, 0x3d, 0x33, 0x21, 0x2f, 0x05, 0x0b, 0x19,
0x17,
        0x76, 0x78, 0x6a, 0x64, 0x4e, 0x40, 0x52,
0x5c, 0x06, 0x08, 0x1a, 0x14, 0x3e, 0x30, 0x22,
0x2c,
        0x96, 0x98, 0x8a, 0x84, 0xae, 0xa0, 0xb2,
0xbc, 0xe6, 0xe8, 0xfa, 0xf4, 0xde, 0xd0, 0xc2,
0xcc,
        0x41, 0x4f, 0x5d, 0x53, 0x79, 0x77, 0x65,
0x6b, 0x31, 0x3f, 0x2d, 0x23, 0x09, 0x07, 0x15,
0x1b,
```

```
        0xa1, 0xaf, 0xbd, 0xb3, 0x99, 0x97, 0x85,
0x8b, 0xd1, 0xdf, 0xcd, 0xc3, 0xe9, 0xe7, 0xf5,
0xfb,
        0x9a, 0x94, 0x86, 0x88, 0xa2, 0xac, 0xbe,
0xb0, 0xea, 0xe4, 0xf6, 0xf8, 0xd2, 0xdc, 0xce,
0xc0,
        0x7a, 0x74, 0x66, 0x68, 0x42, 0x4c, 0x5e,
0x50, 0x0a, 0x04, 0x16, 0x18, 0x32, 0x3c, 0x2e,
0x20,
        0xec, 0xe2, 0xf0, 0xfe, 0xd4, 0xda, 0xc8,
0xc6, 0x9c, 0x92, 0x80, 0x8e, 0xa4, 0xaa, 0xb8,
0xb6,
        0x0c, 0x02, 0x10, 0x1e, 0x34, 0x3a, 0x28,
0x26, 0x7c, 0x72, 0x60, 0x6e, 0x44, 0x4a, 0x58,
0x56,
        0x37, 0x39, 0x2b, 0x25, 0x0f, 0x01, 0x13,
0x1d, 0x47, 0x49, 0x5b, 0x55, 0x7f, 0x71, 0x63,
0x6d,
        0xd7, 0xd9, 0xcb, 0xc5, 0xef, 0xe1, 0xf3,
0xfd, 0xa7, 0xa9, 0xbb, 0xb5, 0x9f, 0x91, 0x83,
0x8d};

// Auxiliary function for KeyExpansion
void KeyExpansionCore(unsigned char *in, unsigned
char i) {
    // Rotate left by one byte: shift left
    unsigned char t = in[0];
    in[0] = in[1];
    in[1] = in[2];
```

```
    in[2] = in[3];
    in[3] = t;

    // S-box 4 bytes
    in[0] = s[in[0]];
    in[1] = s[in[1]];
    in[2] = s[in[2]];
    in[3] = s[in[3]];

    // RCon
    in[0] ^= rcon[i];
}

void KeyExpansion(unsigned char inputKey[16],
unsigned char expandedKeys[176]) {
    // The first 128 bits are the original key
    for (int i = 0; i < 16; i++) {
        expandedKeys[i] = inputKey[i];
    }

    int bytesGenerated = 16;  // Bytes we've
generated so far
    int rconIteration = 1;    // Keeps track of
rcon value
    unsigned char tmpCore[4]; // Temp storage for
core

    while (bytesGenerated < 176) {
        /* Read 4 bytes for the core
```

```
         * They are the previously generated 4
bytes
         * Initially, these will be the final 4
bytes of the original key
         */
        for (int i = 0; i < 4; i++) {
            tmpCore[i] = expandedKeys[i +
bytesGenerated - 4];
        }

        // Perform the core once for each 16 byte
key
        if (bytesGenerated % 16 == 0) {
            KeyExpansionCore(tmpCore,
rconIteration++);
        }

        for (unsigned char a = 0; a < 4; a++) {
            expandedKeys[bytesGenerated] =
expandedKeys[bytesGenerated - 16] ^ tmpCore[a];
            bytesGenerated++;
        }
    }
}

void AddRoundKeyEncrypt(unsigned char *state,
unsigned char *roundKey) {
    for (int i = 0; i < 16; i++) {
        state[i] ^= roundKey[i];
```

```
    }
}

void SubBytesEncrypt(unsigned char *state) {
    for (int i = 0; i < 16; i++) {
        state[i] = s[state[i]];
    }
}

// Shift left, adds diffusion
void ShiftRowsEncrypt(unsigned char *state) {
    unsigned char tmp[16];

    /* Column 1 */
    tmp[0] = state[0];
    tmp[1] = state[5];
    tmp[2] = state[10];
    tmp[3] = state[15];

    /* Column 2 */
    tmp[4] = state[4];
    tmp[5] = state[9];
    tmp[6] = state[14];
    tmp[7] = state[3];

    /* Column 3 */
    tmp[8] = state[8];
    tmp[9] = state[13];
    tmp[10] = state[2];
```

```
    tmp[11] = state[7];

    /* Column 4 */
    tmp[12] = state[12];
    tmp[13] = state[1];
    tmp[14] = state[6];
    tmp[15] = state[11];

    for (int i = 0; i < 16; i++) {
        state[i] = tmp[i];
    }
}

/* MixColumns uses mul2, mul3 look-up tables
 * Source of diffusion
 */
void MixColumns(unsigned char *state) {
    unsigned char tmp[16];

    tmp[0] = (unsigned char)mul2[state[0]] ^
mul3[state[1]] ^ state[2] ^ state[3];
    tmp[1] = (unsigned char)state[0] ^
mul2[state[1]] ^ mul3[state[2]] ^ state[3];
    tmp[2] = (unsigned char)state[0] ^ state[1] ^
mul2[state[2]] ^ mul3[state[3]];
    tmp[3] = (unsigned char)mul3[state[0]] ^
state[1] ^ state[2] ^ mul2[state[3]];
```

```
    tmp[4] = (unsigned char)mul2[state[4]] ^
mul3[state[5]] ^ state[6] ^ state[7];
    tmp[5] = (unsigned char)state[4] ^
mul2[state[5]] ^ mul3[state[6]] ^ state[7];
    tmp[6] = (unsigned char)state[4] ^ state[5] ^
mul2[state[6]] ^ mul3[state[7]];
    tmp[7] = (unsigned char)mul3[state[4]] ^
state[5] ^ state[6] ^ mul2[state[7]];

    tmp[8] = (unsigned char)mul2[state[8]] ^
mul3[state[9]] ^ state[10] ^ state[11];
    tmp[9] = (unsigned char)state[8] ^
mul2[state[9]] ^ mul3[state[10]] ^ state[11];
    tmp[10] = (unsigned char)state[8] ^ state[9] ^
mul2[state[10]] ^ mul3[state[11]];
    tmp[11] = (unsigned char)mul3[state[8]] ^
state[9] ^ state[10] ^ mul2[state[11]];

    tmp[12] = (unsigned char)mul2[state[12]] ^
mul3[state[13]] ^ state[14] ^ state[15];
    tmp[13] = (unsigned char)state[12] ^
mul2[state[13]] ^ mul3[state[14]] ^ state[15];
    tmp[14] = (unsigned char)state[12] ^ state[13]
^ mul2[state[14]] ^ mul3[state[15]];
    tmp[15] = (unsigned char)mul3[state[12]] ^
state[13] ^ state[14] ^ mul2[state[15]];

    for (int i = 0; i < 16; i++) {
        state[i] = tmp[i];
```

```
    }
}

/* Each round operates on 128 bits at a time
 * The number of rounds is defined in AESEncrypt()
 */
void RoundEncrypt(unsigned char *state, unsigned
char *key) {
    SubBytesEncrypt(state);
    ShiftRowsEncrypt(state);
    MixColumns(state);
    AddRoundKeyEncrypt(state, key);
}

void FinalRoundEncrypt(unsigned char *state,
unsigned char *key) {
    SubBytesEncrypt(state);
    ShiftRowsEncrypt(state);
    AddRoundKeyEncrypt(state, key);
}

void AESEncrypt(unsigned char *message, unsigned
char *expandedKey, unsigned char *encryptedMessage)
{
    unsigned char state[16]; // Stores the first 16
bytes of original message

    for (int i = 0; i < 16; i++) {
        state[i] = message[i];
```

```
    }

    int numberOfRounds = 9;

    AddRoundKeyEncrypt(state, expandedKey); //
Initial round

    for (int i = 0; i < numberOfRounds; i++) {
        RoundEncrypt(state, expandedKey + (16 * (i
+ 1)));
    }

    FinalRoundEncrypt(state, expandedKey + 160);

    // Copy encrypted state to buffer
    for (int i = 0; i < 16; i++) {
        encryptedMessage[i] = state[i];
    }
}

// DEcryption
void SubRoundKeyDecrypt(unsigned char *state,
unsigned char *roundKey) {
    for (int i = 0; i < 16; i++) {
        state[i] ^= roundKey[i];
    }
}
```

```
/* InverseMixColumns uses mul9, mul11, mul13, mul14
look-up tables
 * Unmixes the columns by reversing the effect of
MixColumns in encryption
 */
void InverseMixColumnsDecrypt(unsigned char *state)
{
    unsigned char tmp[16];

    tmp[0] = (unsigned char)mul14[state[0]] ^
mul11[state[1]] ^ mul13[state[2]] ^ mul9[state[3]];
    tmp[1] = (unsigned char)mul9[state[0]] ^
mul14[state[1]] ^ mul11[state[2]] ^
mul13[state[3]];
    tmp[2] = (unsigned char)mul13[state[0]] ^
mul9[state[1]] ^ mul14[state[2]] ^ mul11[state[3]];
    tmp[3] = (unsigned char)mul11[state[0]] ^
mul13[state[1]] ^ mul9[state[2]] ^ mul14[state[3]];

    tmp[4] = (unsigned char)mul14[state[4]] ^
mul11[state[5]] ^ mul13[state[6]] ^ mul9[state[7]];
    tmp[5] = (unsigned char)mul9[state[4]] ^
mul14[state[5]] ^ mul11[state[6]] ^
mul13[state[7]];
    tmp[6] = (unsigned char)mul13[state[4]] ^
mul9[state[5]] ^ mul14[state[6]] ^ mul11[state[7]];
    tmp[7] = (unsigned char)mul11[state[4]] ^
mul13[state[5]] ^ mul9[state[6]] ^ mul14[state[7]];
```

```
    tmp[8] = (unsigned char)mul14[state[8]] ^
mul11[state[9]] ^ mul13[state[10]] ^
mul9[state[11]];
    tmp[9] = (unsigned char)mul9[state[8]] ^
mul14[state[9]] ^ mul11[state[10]] ^
mul13[state[11]];
    tmp[10] = (unsigned char)mul13[state[8]] ^
mul9[state[9]] ^ mul14[state[10]] ^
mul11[state[11]];
    tmp[11] = (unsigned char)mul11[state[8]] ^
mul13[state[9]] ^ mul9[state[10]] ^
mul14[state[11]];

    tmp[12] = (unsigned char)mul14[state[12]] ^
mul11[state[13]] ^ mul13[state[14]] ^
mul9[state[15]];
    tmp[13] = (unsigned char)mul9[state[12]] ^
mul14[state[13]] ^ mul11[state[14]] ^
mul13[state[15]];
    tmp[14] = (unsigned char)mul13[state[12]] ^
mul9[state[13]] ^ mul14[state[14]] ^
mul11[state[15]];
    tmp[15] = (unsigned char)mul11[state[12]] ^
mul13[state[13]] ^ mul9[state[14]] ^
mul14[state[15]];

    for (int i = 0; i < 16; i++) {
        state[i] = tmp[i];
    }
```

```
}

// Shifts rows right (rather than left) for
decryption
void ShiftRowsDecrypt(unsigned char *state) {
    unsigned char tmp[16];

    /* Column 1 */
    tmp[0] = state[0];
    tmp[1] = state[13];
    tmp[2] = state[10];
    tmp[3] = state[7];

    /* Column 2 */
    tmp[4] = state[4];
    tmp[5] = state[1];
    tmp[6] = state[14];
    tmp[7] = state[11];

    /* Column 3 */
    tmp[8] = state[8];
    tmp[9] = state[5];
    tmp[10] = state[2];
    tmp[11] = state[15];

    /* Column 4 */
    tmp[12] = state[12];
    tmp[13] = state[9];
    tmp[14] = state[6];
```

```
    tmp[15] = state[3];

    for (int i = 0; i < 16; i++) {
        state[i] = tmp[i];
    }
}

/* Perform substitution to each of the 16 bytes
 * Uses inverse S-box as lookup table
 */
void SubBytesDecrypt(unsigned char *state) {
    for (int i = 0; i < 16; i++) { // Perform
substitution to each of the 16 bytes
        state[i] = inv_s[state[i]];
    }
}

/* Each round operates on 128 bits at a time
 * The number of rounds is defined in AESDecrypt()
 * Not surprisingly, the steps are the encryption
steps but reversed
 */
void RoundDecrypt(unsigned char *state, unsigned
char *key) {
    SubRoundKeyDecrypt(state, key);
    InverseMixColumnsDecrypt(state);
    ShiftRowsDecrypt(state);
    SubBytesDecrypt(state);
}
```

```
// Same as RoundDecrypt() but no InverseMixColumns
void InitialRoundDecrypt(unsigned char *state,
unsigned char *key) {
    SubRoundKeyDecrypt(state, key);
    ShiftRowsDecrypt(state);
    SubBytesDecrypt(state);
}

/* The AES decryption function
 * Organizes all the decryption steps into one
function
 */
void AESDecrypt(unsigned char *encryptedMessage,
unsigned char *expandedKey, unsigned char
*decryptedMessage) {
    unsigned char state[16]; // Stores the first 16
bytes of encrypted message

    for (int i = 0; i < 16; i++) {
        state[i] = encryptedMessage[i];
    }

    InitialRoundDecrypt(state, expandedKey + 160);

    int numberOfRounds = 9;

    for (int i = 8; i >= 0; i--) {
```

```
        RoundDecrypt(state, expandedKey + (16 * (i
+ 1)));
    }

    SubRoundKeyDecrypt(state, expandedKey); //
Final round

    // Copy decrypted state to buffer
    for (int i = 0; i < 16; i++) {
        decryptedMessage[i] = state[i];
    }
}

int main() {

    cout << "AES Algorithm" << endl;
    cout << "Enter 1 for encryption \n 2 for
decryption" << endl;
    int choice;
    cin >> choice;
    if (choice == 1) {
        char message[1024];

        cout << "Enter the message to encrypt: ";
        cin.getline(message, sizeof(message));
        cout << message << endl;

        // Pad message to 16 bytes
```

```
        int originalLen = strlen((const char
*)message);

        int paddedMessageLen = originalLen;

        if ((paddedMessageLen % 16) != 0) {
            paddedMessageLen = (paddedMessageLen /
16 + 1) * 16;
        }

        unsigned char *paddedMessage = new unsigned
char[paddedMessageLen];
        for (int i = 0; i < paddedMessageLen; i++)
{
            if (i >= originalLen) {
                paddedMessage[i] = 0;
            } else {
                paddedMessage[i] = message[i];
            }
        }

        unsigned char *encryptedMessage = new
unsigned char[paddedMessageLen];

        string str;
        ifstream infile;
        infile.open("keyfile", ios::in |
ios::binary);
```

```
        if (infile.is_open()) {
            getline(infile, str); // The first line
of file should be the key
            infile.close();
        }

        else
            cout << "Unable to open file";

        istringstream hex_chars_stream(str);
        unsigned char key[16];
        int i = 0;
        unsigned int c;
        while (hex_chars_stream >> hex >> c) {
            key[i] = c;
            i++;
        }

        unsigned char expandedKey[176];

        KeyExpansion(key, expandedKey);

        for (int i = 0; i < paddedMessageLen; i +=
16) {
            AESEncrypt(paddedMessage + i,
expandedKey, encryptedMessage + i);
        }
```

```
        cout << "Encrypted message in hex:" <<
endl;
        for (int i = 0; i < paddedMessageLen; i++)
{
            cout << hex <<
(int)encryptedMessage[i];
            cout << " ";
        }

        cout << endl;

        // Write the encrypted string out to file
"message.aes"
        ofstream outfile;
        outfile.open("message.aes", ios::out |
ios::binary);
        if (outfile.is_open()) {
            outfile << encryptedMessage;
            outfile.close();
            cout << "Wrote encrypted message to
file message.aes" << endl;
        }

        else
            cout << "Unable to open file";

        // Free memory
        delete[] paddedMessage;
        delete[] encryptedMessage;
```

```
    } else if (choice == 2) {
        string msgstr;
        ifstream infile;
        infile.open("message.aes", ios::in |
ios::binary);

        if (infile.is_open()) {
            getline(infile, msgstr); // The first
line of file is the message
            cout << "Read in encrypted message from
message.aes" << endl;
            infile.close();
        }

        else
            cout << "Unable to open file";

        char *msg = new char[msgstr.size() + 1];

        strcpy(msg, msgstr.c_str());

        int n = strlen((const char *)msg);

        unsigned char *encryptedMessage = new
unsigned char[n];
        for (int i = 0; i < n; i++) {
            encryptedMessage[i] = (unsigned
char)msg[i];
        }
```

```
        // Free memory
        delete[] msg;

        // Read in the key
        string keystr;
        ifstream keyfile;
        keyfile.open("keyfile", ios::in |
ios::binary);

        if (keyfile.is_open()) {
            getline(keyfile, keystr); // The first
line of file should be the key
            cout << "Read in the 128-bit key from
keyfile" << endl;
            keyfile.close();
        }

        else
            cout << "Unable to open file";

        istringstream hex_chars_stream(keystr);
        unsigned char key[16];
        int i = 0;
        unsigned int c;
        while (hex_chars_stream >> hex >> c) {
            key[i] = c;
            i++;
        }
```

```
        unsigned char expandedKey[176];

        KeyExpansion(key, expandedKey);

        int messageLen = strlen((const char
*)encryptedMessage);

        unsigned char *decryptedMessage = new
unsigned char[messageLen];

        for (int i = 0; i < messageLen; i += 16) {
            AESDecrypt(encryptedMessage + i,
expandedKey, decryptedMessage + i);
        }

        cout << "Decrypted message in hex:" <<
endl;
        for (int i = 0; i < messageLen; i++) {
            cout << hex <<
(int)decryptedMessage[i];
            cout << " ";
        }
        cout << endl;
        cout << "Decrypted message: ";
        for (int i = 0; i < messageLen; i++) {
            cout << decryptedMessage[i];
        }
        cout << endl;
```

```
    } else {
        cout << "Invalid choice" << endl;
    }
}
```

Output:

```
Rutikesh@Rutikesh MINGW64 ~/Desktop/FY I/C&NS Lab/Assignment 8
$ ./a.exe
AES Algorithm
Enter 1 for encryption
 2 for decryption
1
Enter the message to encrypt:
Encrypted message in hex:

Wrote encrypted message to file message.aes

Rutikesh@Rutikesh MINGW64 ~/Desktop/FY I/C&NS Lab/Assignment 8
$ ./a.exe
AES Algorithm
Enter 1 for encryption
 2 for decryption
2
Read in encrypted message from message.aes
Read in the 128-bit key from keyfile
Decrypted message in hex:
ad de 44 40 95
Decrypted message: ¡ D@ò
```